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PREFACE

This publication is a complication of summaries of reports written by Principal Investigators funded through the Planetary Astronomy Program of NASA's Solar System Exploration Division, Office of Space Science and Applications.

The summaries are designed to provide information about current scientific research projects conducted in the Planetary Astronomy Program and to facilitate communications and coordination among concerned scientists and interested persons in universities, government, and industry.

The reports are published as they were submitted by the Principal Investigators and have not been edited. They are arranged in alphabetical order.

In a second section, highlights of recent accomplishments in Planetary Astronomy are summarized as they were submitted by the principal investigators. The name attached to an individual paragraph is generally the name of the person who submitted that paragraph.

Jurgen Rahe
Discipline Scientist
Planetary Astronomy Program
Solar System Exploration Division

June 1988

LIST OF PRINCIPAL INVESTIGATORS

A'Hearn, M. F.	UMD	Observation of Comets and Asteroids
A'Hearn, M. F.	UMD	Theoretical Spectroscopy of Comets
Atreya, S. K.	UMN	Gaseous Cometary Coronae
Baum, W. A.	LWEL	Planetary Research at Lowell Observatory
Beebe, R. F.	NMSU	Long-Term Changes in Reflectivity and Larger Scale Motions in the Atmospheres of Jupiter and Saturn
Bell, J. F.	UHI	Infrared Spectral Studies of Asteroids
Belton, M. J. S.	KPNO	Time Variable Phenomena in the Jovian System
Belton, M. J. S.	KPNO	Reduction and Analysis of Photometric Data on Comet Halley
Bergstralh, J. T.	JPL	Planetary Spectroscopy
Binzel, R. P.	PSI	Photometry of Pluto-Charon Mutual Events and Hirayama Family Asteroids
Bowell, E.	LWEL	Studies of Asteroids, Comets and Jupiter's Outer Satellites
Brandt, J. C.	UCO	Evolution of Large Scale Plasma Structures in Comets: Kinematics and Physics
Brown, R. H.	JPL	Infrared Observations of Small Solar-System Bodies

Campbell, D. B.	NAIC	Arecibo S-Band Radar Program
Chapman, C. R.	PSI	Planetary Astronomy
Combi, M. R.	AER	Imaging and Spectroscopy of Comet P/Halley
Crisp, D.	JPL	Near IR-Observations of Venus
Cruikshank, D. P.	ARC	Research in Planetary Astronomy and Operation of Mauna Kea Observatory
Deming, D.	GSFC	Spectroscopic Planetary Detection
Drummond, J. D.	UAZ	Speckle Interferometry of Asteroids
Elliot, J. L.	MIT	Portable High Speed Photometry Systems for Occultations
Fink, U.	UAZ	Planetary Spectroscopy
Gatewood, G. D.	PITT	The University of Pittsburgh's Allegheny Observatory Search of Planetary Systems
Gehrels, T.	UAZ	CCD Scanning for Asteroids and Comets
Goldberg, B. A.	JPL	High Resolution Imaging of Solar System Objects
Greenberg, R. J.	UAZ	Planetary Astronomy: Rings, Satellites, and Asteroids

Gulkis, S.	JPL	Submillimeter Heterodyne Receiver for the CSO Telescope
Hanner, M. S.	JPL	Infrared Observations of Periodic Comets
Harris, A. W.	JPL	Table Mountain Observatory Support to Other Programs
Helin, E. F.	JPL	Planet-Crossing Asteroid Survey (PCAS)
Holberg, J. B.	UAZ	Voyager UVS Data Analysis
Howell, R. R.	UWY	IR Speckle Interferometry and Spectroscopy of Comets
Hubbard, W. B.	UAZ	Interiors of the Giant Planets
Hunten, D. M.	UAZ	Studies of Extended Planetary Atmospheres
Irvine, W. M.	UMA	Radiative Transfer in Planetary Atmospheres
Jackson,, W. M.	UCD	Laboratory Simulation of the Surface of Halley's Comet
Jennings, D. E.	GSFC	Ground Based Infrared Astronomy
Jewitt, D.	MIT	Optical Investigation of Comet Halley
Johnson, T. V.	JPL	Infrared Observations of Outer Planet Satellites
Jurgens, R. F.	JPL	Goldstone Solar System Radar

Jurgens, R. F.	JPL	Radar Observations of the Inner Solar System
Klein, M. J.	JPL	Planetary Submillimeter Spectroscopy
Knacke, M. J.	SUNY	Infrared Spectroscopy of Jupiter and Saturn
Kostiuk, T.	GSFC	Advanced Infrared Astronomy
Larson, S.	UAZ	Cometary Spectroscopy and Imaging
Lebofsky, L. A.	UAZ	Infrared Observations of Solar System Objects
Lutz, B. L.	LWEL	Outer Planet Studies
Matson, D. L.	JPL	Asteroid Team
McCord, T. B.	UHI	Research in Planetary Astronomy
McCrosky, R. E.	SAO	Prairie Network Geminid Fireballs
McCrosky, R. E.	SAO	Astrometric Observations of Comet and Asteroids and Subsequent Orbital Investigations
McFadden, L. A.	UMD	Asteroid and Comet Surfaces
McMillian, R. S.	UAZ	The Radial Velocity Search for Extra-Solar Planets
Millis, R. L.	LWEL	Occultation Studies of the Solar System
Muhleman, D. O.	CIT	Lunar and Planetary Studies
Muhleman, D. O.	CIT	Submillimeter and Millimeter Observations of Solar System Objects

Neff, J. S.	UIA	Photometry of Comet Halley
Newburn, R. L., Jr.	JPL	Physical Processes in Comets
Niedner, M. B.	GSFC	Imaging Studies of Comets
Oliversen, R. G.	GSFC	CCD Camera System for Cometary Research
Orton, G. S.	JPL	Infrared Observations of Planetary Atmospheres
Ostro, S. J.	JPL	Radar Innvestigation of Asteroids and Planetary Satellites
Owen, T.	SUNY	Spectroscopic Observations of the Planets
Potter, A. E.	JSC	Atmospheric Surface Compositional Studies of Mercury and the Moon
Scherb, F.	UWI	Fabry-Perot Ground-Based Observations of Comets and the Jupiter Io-Plasma Torus
Shapiro, I. I.	SAO	Radar Studies in the Solar System
Smith, B. A.	UAZ	Studies in Planetary Sciences
Smith, H. J.	UTX	A Continued Program of Planetary Study
Smith, W. H.	WAU	Ground-Based Spectropolarimetric Studies of the Outer Planets and Titan. High Resolution Spectral Imagery for Periodic and New Comets

Snyder, L. E.	UIL	VLA Studies of Comets
Soifer, B. T.	CIT	Research at Palomar Observatory in Planetary Astronomy
Spinrad, H.	UCB	Spatially Resolved Quantitive Spectroscopy of Comets
Strom, S. E.	UMA	The Evolution of Young Stellar Object Disks and their Environment
Taylor, R.	UAZ	Pole Orientation, Sidereal Period, and Sense of Rotation of Asteroids
Tedesco, E. F.	JPL	Asteroid Shapes and Pole Orientations from Visual and Infrared Photometry
Telesco, C. M.	MSC	Infrared Imaging of Comets
Terrile, R. J.	JPL	Planetary Optical and Infrared Imaging
Trauger, J. T.	JPL	Planetary Fabry-Perot Spectroscopy
Valero, F. P. J.	ARC	Planetary Astronomy and Supporting Laboratory Research
Veeder, G. J.	JPL	Physical Properties of Asteroids
Vilas, F.	JSC	Compositional Studies of Primitive Asteroids
Webster, W. J., Jr.	GSFC	Passive Mircrowave Remote Sensing of Asteroids Using the VLA

Williams, J. G.	JPL	Astrometric Observations of Asteroids and Small Bodies
Wisniewski, W. Z.	UAZ	Photometry of Asteroids and Comet Cores
Wyckoff, S.	ASU	Chemical Abundances of Comets
Yeomans, D. K.	JPL	Comet and Asteroid Dynamics

HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

CONTENTS

N89-16625

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Observations of Comets and Asteroids

PERFORMING ORGANIZATION

Astronomy Program
University of Maryland
College Park, MD 20742

INVESTIGATOR'S NAME

Michael F. A'Hearn

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy We use all available ground-based observational techniques to study the chemical and physical properties of the small bodies of the solar system, primarily comets and secondarily asteroids. The ultimate goal is to use these bodies to understand the formation and evolution of the solar system.

b. Accomplishments 1987-1988. (i) continued the analysis of ccd images of comet P/Halley. This included a major revision of our paper on the periodicities of CN jets in Halley showing that their periodicity is 7.3 days, not 2.2 days. It also included an analysis of the continuum images which showed that the dust in jets is much redder than in the "ambient" coma. Calculations with Mie theory sugest that the particles which must be "added" in the jets to make them red are exactly those particles that show the strongest effects of radiation pressure. Much effort was expended devising methods to estimate the level of sky background of the many images in which the comet extends to the edge of the chip. Profile-fitting to determine the asymptote seems to work but is very sensitive to the portion of the comet over which the image is fit. (ii) Examined images of comet Wilson taken over many months in 1987. Wilson, a dynamically new comet, shows none of the short-term variability or jet structure (either dusty jets or jets of radicals seen in Halley. This is presumably due to the lack of a mantle or the nucleus. (iii) Developed median-imaging of sky as a technique for removing residual flat-fielding errors in ccd images. (iv) Developed a Monte Carlo model and a convulution model for studying temporal variability of gaseous daughter products. (v) Wrote several review papers. (vi) Began reduction of a Pluto-Charon mutual event observed with ccd from Perth.

c Plan for Next Year (i) Archiving all ccd data with IHW. (ii) Further reduction of ccd images of Halley and Wilson beginning with careful subtraction of continuum from emission-band images. (iii) Complete model for temporal variability and apply to Halley to determine lifetimes of parents. (iv) Continue ccd observations of comets.

d. Publications 1987-1988

Observations of Comets and Asteroids - NSG 7322

A'Hearn, M.F. 1988 Observations of Cometary Nuclei in Ann. Rev. Earth, Planet. Sci, 16, 273-293.

Birch, P.F, Bowers, C.L, and A'Hearn, M.F., 1987, The 1987 May 28th Inferior Conjunction of the Pluto/Charon System. The Australian Physicist 24, 222-223.

Hoban S., A'Hearn, M.F. and Birch, P.V., 1988 Variationsin the Size Distribution of Dust in P/Halley, Manuscript being edited for submission to Icarus.

*Hoban S., Samarasinha, N.H., A'Hearn, M.F. and Klinglesmith, D.A. 1988, An Investigation into Periodicities in the Morphology of CN Jets in Comet P/Halley, Astron. Astrophys. 195, 331-337.

*Millis, R.L, A'Hearn, M.F., and Campins, H., 1988, An Investigation of the Nucleus and Coma of Comet Arend-Rigaux, Ap.J. 324, 1194-1209.

*Millis, R. L. ... A'Hearn, M.F. Schnuur, R.G. ... 1987, The Size, Shape, Density and Albedo of Ceres from its Occultation of BD+8°47', Icarus 72, 507-518.

Weissman, P.R., A'Hearn, M.F., McFadden, L.A. and Rickman, H., 1988, Evolution of Comets into Asteroids, to appear in "Asteroids", book based on "Asteroids II", meeting in Tucson, April 1988.

* These items listed as submitted on last year's T43 .
Investigators supported by this grant.

N89-16626

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Theoretical Spectroscopy of Comets

PERFORMING ORGANIZATION

Astronomy Program
University of Maryland
College Park, MD 20742

INVESTIGATOR'S NAME

Michael F. A'Hearn

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy We calculate theoretical spectra of various emitting species in cometary comae both to investigate physical parameters that are measureable with cometary spectra and to provide fluorescence efficiencies for the derivation of abundances from fluxes.

b. Progress and Accomplishments 1987-1988. (i) Completed paper on NH. NH is much further from nucleus than previously thought and, because previous fluorescence efficiencies were much too high, NH is 5 times more abundant than previously thought. (ii) Analyzed spectrum of S_2 in comet I-A-A. Despite its short lifetime, S_2 reaches fluorescent equlibrium. The equilibrium spectrum matches the relative band strengths in IUE spectra much better than does single cycle fluorescence. Equilibrium (but not single-cycle) flurescence also predicts strong optical emission bands which are seen in ground-based spectra of comet I-A-A. Equilibrium fluorescence efficiencies are much higher than single-cycle fluorescence efficiencies implying S_2 only half as abundant as previously estimated. (iii) Fluorescence spectrum of SO calculated and compared with several IUE spectra including those in which Wallis and Krishna Swamy claim SO to be present. Relative intensities and shapes of bands are inconsistent with any real identification. Upper limit on SO column density roughly 20 times column density of S_2 ; not a useful limit for chemical models.
(iv) Completed an updated analysis of fluorescence by OH including studies of the Greenstein effect and quenching the Λ-doublet inversion. The Greenstein effect was measured in old IUE spectra of Comet Encke (1980) and used to show that the radial component of the non-gravitational force is very asymetric about perihelion.

c. Tasks for Next Year (i) Complete papers for items 2 and 3 above. (ii) Model infrared (TKS-Vega) spectrum of Halley to determine relative contributions of OH fluorescence, nascent OH created in excited vibrational/rotational states, and H_2O. (iii) calculate synthetic spectra of CH for comparison with ground-based data. (iv) Study additional factors affecting the NH spectrum (eg. infrared emission by dust in the coma) and consider the levels in more detail to search for laser/maser action as suggested by Litvak.

d. Publications 1987-1988

Theoretical Specroscopy of Comets - NAGW 902

Kim, S.J. A'Hearn M.F. and Cochran, W.D 1988, NH Emissions in Comets: Fluorescence vs. Collisions, Icarus, in press.

A'Hearn, M.F. 1988, Comets in A Decade of Uv Astronomy with IUE, in press.

Schleicher, D.G. and A'Hearn, M.F. 1988, The Fluorescence of Cometary OH, Ap.J. in press.

A'Hearn, M.F. and Schliecher, D.G. 1988, Comet P/Encke's Non-Gravitational Force , Ap.J. Letters in press.

Kim, S.J. A'Hearn, M.F. and Larson, S.M., 1988 S_2 Fluorescence Processes, manuscript being edited for submission to Icarus.

Kim, S.J. and A'Hearn, M.F. 1988 Upper Limit on the Abundance of SO in Comets I-A-A and Halley, manuscript being edited for submission to Icarus.

Investigators supported by this grant
Abstracts of talks not included.

N89-16627

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Gaseous Cometary Coronal/NAGW-1158

PERFORMING ORGANIZATION

The University of Michigan
Department of Atmospheric, Oceanic and Space Sciences
Ann Arbor, MI 48109-2143

INVESTIGATOR'S NAME

Sushil K. Atreya

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: Ground-based observations of coma emission line profiles permit direct insight into the composition and kinetic state of a cometary atmosphere and in turn provide much needed constraints in reconstructing a comet's history; the profiles themselves yield information on the mechanisms generating the observed species, while their intensities correspond to overall production rates by the nucleus. Intensities and line profiles at wavelengths 6562.7A (H-alpha) and 6300.3A ($O(^1D)$ decay) were obtained for Comet Halley in the period March-April 1986 and for Comet Wilson in the period March 1987 using the Fabry-Perot optical facility at Arecibo; the Comet Halley observations have been undergoing careful analysis as the main effort of this project.

b. Accomplishments: Attention has centered on $O(^1D)$ 6300A observations obtained over four consecutive nights in April 1986. Surprisingly, the sorts of profiles to be expected in coma observations have not been theoretically developed in the past, necessitating our reappraisal of this question. It turns out that coma profiles vary noticeably according to excitation mechanism, and the proper interpretation of a profile requires the use of the appropriate model type. A paper cataloging the basic types and their interpretation will be submitted for publication in a few months. The intensities of the 6300A emission can be used independently to estimate the production rate of H_2O by the comet nucleus; indeed, this may be the most reliable way of determining this basic quantity using ground-based facilities. The H_2O production rates implied by our observations throughout the period March-April 1986 have been derived and are to be presented at the upcoming COSPAR special session "Aeronomy of Comets and Outer Planets."

c. Anticipated Accomplishments: Armed with a firmer understanding of how to interpret profiles and the experience gained with the peculiarities of coma observations, new instrumental goals can be defined that will be better suited for future observations (in particular, ground-based support of a CRAF-type mission). We also anticipate sharing data with other groups (notably, Roesler's group at the University of Wisconsin); it is hoped that further insight into the kinetic state of the Halley coma near the time of the spacecraft encounters will be gained when the profiles are analysed using the new interpretational tools. We also anticipate reducing the Comet Wilson data for comparison with the completed analysis of our Comet Halley observations.

d. Publications

Bishop, J., and S.K. Atreya [1988] Cometary line profiles, manuscript in preparation.

Kerr, R.B., C.A. Tepley, R.P. Cageao, S.K. Atreya, T.M. Donahue, and I.M. Cherchneff [1987] Observations of Comet Halley at H-alpha and 6300A. Geophys. Res. Lett. **14**, 53-56.

Kerr, R.B., et al. [1988] Ground-based observations of cometary coma at H-alpha and 6300A: A Review. To be submitted to Adv. Space Res.

N89-16628

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Research at Lowell Observatory
NGR-03-003-001

PERFORMING ORGANIZATION

Lowell Observatory
Mars Hill Road
Flagstaff, Arizona 86001

INVESTIGATOR'S NAME

William A. Baum
602-774-3358

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Research under this grant currently deals largely with comets. Scientific goals include a better determination of the basic physical characteristics of cometary nuclei, a more complete understanding of the complex processes in the comae, a survey of abundances and gas/dust ratios in a large number of comets, and a measurement of primordial $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios. Our program also includes the observation of Pluto-Charon mutual eclipses to derive dimensions.

(b) During the reporting period we completed reduction and analysis of extensive narrowband photometry of Comet Halley from Cerro Tololo Inter-American Observatory, Perth Observatory, Lowell Observatory, and Mauna Kea Observatory. We have shown that the 7.4-day periodicity in the activity of Comet Halley, discovered earlier by Millis and Schleicher, was present from late February through at least early June 1986, but there is no conclusive evidence of periodic variability in the preperihelion data. Greatly improved NH scalelengths and lifetimes have been derived from the Halley data which lead to the conclusion that the abundance of NH in comets is much higher than previously believed. Simultaneous optical and thermal infrared observations were obtained of Comet P/Tempel 2 (in collaboration with M.F. A'Hearn and H. Campins) using the MKO 2.2 m telescope and the NASA IRTF. Preliminary analysis of these observations shows that the comet's nucleus is highly elongated, very dark, and quite red. We obtained CCD imaging observations of Comets P/Borrelly, Furuyama, Bradfield, Liller, and P/Tempel 2. CCD luminosity profiles of 14 selected comets were prepared for publication, and work was continued on the modeling of continuum luminosity profiles in terms of radiation pressure and grain evolution. Analysis of high-resolution spectra of P/Halley, recorded in the region of the CN violet bands, was begun for the purpose of extracting the $^{12}C/^{13}C$ ratio in this molecule. Two Pluto-Charon mutual events were observed. Narrowband CCD imaging of Jupiter with methane and ammonia filters was explored. In August we hosted an international workshop on *Time-Variable Phenomena in the Jovian System*, in which 115 planetary scientists participated.

(c) Major papers discussing the periodic variability and overall photometric behavior of Comet Halley will be completed and published. Analysis of the optical and infrared observations of Comet P/Tempel 2 will be completed and the results published. Existing photometry of more than 70 comets which we have observed since 1976 will be reduced to a common photometric system and the results discussed in terms of the group properties of comets. Observations of Comet P/Brorsen-Metcalf and other well-placed comets are planned in order to search for periodic variability, test the recent results on NH, and extend our data base. Publication of existing luminosity profile data will be completed, and the modeling of our data in terms of grain properties will be continued. Analyses of high resolution spectra of P/Halley will be extended. We plan to observe several Pluto-Charon events.

d) Bibliography of papers published or in press during the past year.

A'Hearn, M., Campins, H., and Schleicher, D. (1988). The Nucleus of Comet P/Tempel 2. IAU Circular No. 4614.

Baum W. A., Kreidl, T. J., and Schleicher, D. G. (1987). Assaying Cometary Grains. *Bull. Amer. Astron. Soc.* **19**, 868.

Baum, W. A., Kreidl, T. J., and Schleicher, D. G. (1988). Cometary grains. *Astron. J.*, in preparation.

Carlson, B. E., and Lutz, B. L. (1988). Spatial and temporal variations in the atmosphere of Jupiter: Polarimetric and photometric constraints. In *Proceedings of the International Workshop on Time-Variable Phenomena in the Jovian System* NASA Special Publication (eds. M. J. Belton and R. A. West), in press.

Lutz, B. E. (1987). The solar system/interstellar medium connection: gas phase abundances. Invited review in *Interstellar Processes* (eds. D. J. Hollenbach and H. A. Thronson), D. Reidel, Dordrecht.

Millis, R. L., A'Hearn, M. F., and Campins, H. (1988). An investigation of the nucleus and coma of Comet P/Arend-Rigaux. *Astrophys. J.* **324**, 1194-1209.

Millis, R. L., Schleicher, D. G., Birch, P. V., Martin, R., and A'Hearn, M. F. (1987). Production of Gas and Dust by Comet Halley. *Bull. Amer. Astron. Soc.* **19**, 880.

Millis, R. L., Schleicher, and Birch, P. V. (1988). Narrowband Filter Photometry of Comet P/Halley in 1985/1986. In preparation.

Schleicher, D. G., and Millis, R. L. (1988). Revised Scalelengths for Cometary NH. *Astrophys. J.*, submitted.

Schleicher, D. G., Millis, R. L., and Birch, P. V. (1987). Photometric Observations of Comet P/Giacobini-Zinner. *Astron. Astrophys.* **187**, 531-538.

Schleicher, D. G., Millis, R. L., Tholen, D. J., Hammel, H. B., Piscitelli, J. R., Lark, N., Birch, P. V., and Martin, R. (1987). The Variability of Comet Halley During the 1985/1986 Apparition. *Bull. Amer. Astron. Soc.* **19**, 879.

Schleicher, D. G., Millis, R. L., Tholen, D. J., Hammel, H. B., Piscitelli, J. R., Lark, N., Birch, P. V., and Martin, R. (1988). The Variability of Comet Halley During the 1985/1986 Apparition. In preparation.

N89-16629

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

LONG-TERM CHANGES IN REFLECTIVITY AND LARGE SCALE MOTIONS IN THE ATMOSPHERE OF JUPITER AND SATURN

PERFORMING ORGANIZATION

NEW MEXICO STATE UNIVERSITY

INVESTIGATOR'S NAME

RETA BEEBE

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. STRATEGY: A SYSTEMATIC PHOTOGRAPHIC PROGRAM, UTILIZING BROAD-BAND UV, BLUE, GREEN, RED AND NEAR IR PASS-BANDS HAS BEEN CARRIED OUT AT THE 60 CM. TORTUGAS MOUNTAIN TELESCOPE. THIS IS PART OF AN ONGOING PROGRAM THAT SPANS TWO JOVIAN YEARS (25 YRS.) THE PURPOSE OF THIS PROGRAM IS TO PROVIDE AN ONGOING DATABASE TO CHARACTERIZE HIGH RESOLUTION DATA FROM SPACECRAFT AND EARTH-ORBITING OBSERVATORIES.

B. ACCOMPLISHMENTS. THE STANDARD OBSERVING PROGRAM HAS BEEN MAINTAINED AND SUPPORT HAS BEEN GIVEN TO OTHER INVESTIGATORS WHO ARE CARRYING OUT COMPLEMENTARY OBSERVING PROGRAMS. THE GENERAL ASPECT OF THE CLOUD DECKS HAVE BEEN MONITORED, AND REVEAL AN INTERVAL THAT SHOWS LITTLE VARIATION IN THE GENERAL ASPECT OF THE CLOUDDECK OF JUPITER SINCE 1981, WHEN THE NORTH TEMPERATUE BELT DARKENED. A CCD CAMERA HAS BEEN ADAPTED FOR LOW COST OPERATION, UTILIZING AN IBM-AT CLONE FOR DATA ACQUISITION. AN RCA FRAME GRABBER HAS BEEN MODIFIED FOR ENCODING THE ARCHIVAL IMAGES.

C. ANTICIPATED ACCOMPLISHMENTS. WORK HAS BEGUN ON ENCODING, LIMB DARKENING REMOVAL AND MAP PROJECTION TO PRODUCE A SERIES OF CYLINDERICAL MORPHOLOGY MAPS THAT SPAN A PERIOD OF 25 YEARS. THIS SET WILL CHARACTERIZE LONGTERM CHANGES IN THE JOVIAN ATMOSPHERE.

d. Publications:

"Time-Variable Nature of the Jovian Cloud Properties and Thermal Structure: An Observational Perspective" R. F. Beebe, G. S. Orton, and R.A. West. NASA Special Report, Edited by Michael Belton, In Press.

Public Education.

"The Smithsonian Library of the Solar System - Jupiter", R. F. Beebe , Nearing Completion.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

INFRARED SPECTRAL STUDIES OF ASTEROIDS (NAGW 802)

PERFORMING ORGANIZATION

Planetary Geosciences Division / Hawaii Institute of Geophyics
2525 Correa Road / Honolulu, HI 96822

INVESTIGATOR'S NAME

Jeffrey F. Bell

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) *Strategy:* The research objective is to improve our understanding of the surface mineralogy of asteroids and to link the vast existing body of meteorite geochemical data with specific astronomical objects which may be the targets of future NASA missions. The methodology employed is 1) use advanced astronomical instrumentation to obtain reflection spectra in the 0.3-5.2μm wavelength range of selected asteroids; 2) compare the asteroid data with similar data on simulated asteroid regoliths of various compositions to determine the surface mineralogy and meteoritic affinities of asteroid spectral classes and specific asteroids; 3) intergrate the mineralogical information with other astronomical data, orbital dynamics studies, and meterorite geochemistry data to reconstruct the condensational, thermal, and collisional history of the present asteroids and their parent planetesimals; 4) use the information obtained to asist planning of future NASA asteroid missions such as Galileo and CRAF.

b) *Progress* (1987-88): Prepared for final publication of 52-Color Asteroid Survey; continued comprehensive IR spectral survey of S-type asteroids; observed selected members of the Eos family and discovered close spectral similarity to CO/CV chondrites; provided information for selection of candidate asteroid flyby targets for Galileo and CRAF missions; defined new 3-color photometric system in 2.8-3.4μm spectral region for future studies of the bound-water band in this region.

c) *Proposed Research:* Publish 52-color survey spectra; continue to aquire spectra of selected S-type asteroids, Earth-crossers, and members of asteroid dynamical families; continue to assist planning for Galileo and CRAF mission asteroid flybys; possibly begin observing program in mid-IR.

d) *Summary Bibliography* (1987-88): 2 papers published, 1 in press, 3 submitted.

Bell, J. F., and B. R. Hawke, "Recent Comet Impacts on The Moon: The Evidence from Remote Sensing Studies." *Pub. Ast. Soc. Pacific* **99**, 862-867 (1987).

Bell, J. F., and K. Keil, "Spectral Alteration Effects in Chondritic Regolith Breccias", *Proc. Lunar Planet. Sci. Conf. 18th*, (G. Ryder, ed.), Cambridge Univ. Press, 573-580 (March 1988).

Bell, J. F., R. H. Brown, and B. R. Hawke, "Composition and Size of Earth-Crossing Asteroid 1984KB." *Icarus* **73**, 482-486 (1988).

Piscitelli, J. R., D. P. Cruikshank, and J. F. Bell, "Laboratory Studies of Irradiated Nitrogen-Methane Mixtures: Applications to Triton." *Icarus*, in press.

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N89-16631

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

International Workshop on Time-Variable Phenomena in the Jovian System (Publication of Proceedings).

PERFORMING ORGANIZATION

Kitt Peak National Observatory
950 N. Cherry Avenue
Tucson, Arizona 85719

INVESTIGATOR'S NAME

Michael J.S. Belton
R. A. West (Co-Investigator)

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Strategy: Many of the scientifically interesting phenomena that occur in the Jovian system are strongly time variable. Some are episodic (eg. Io volcanism); some are periodic (wave transport in Jupiters atmosphere); and some are exceedingly complex (magnetosphere - Io - Torus-Auroral interactions) and possibly unstable. To investigate this class of phenomena utilizing Voyager data and, in the future, Galileo results, a coherent program of ground based and earth-orbital observations, and of theory that spans the time between the missions, is required. To stimulate and help define the basis of such a scientific program we organized an International Workshop on the subject with the intent of publishing the proceedings which would represent the state of knowledge in 1987.

(b) Accomplishments: We helped organize a workshop on "Time-Variable Phenomena in the Jovian System" that was held 25-27 August, 1987 at the Lowell Observatory in Flagstaff, Arizona. Eighty nine scientists participated in a program that included fifteen invited papers and forty one contributed (posters) papers. One third of the workshop was devoted to oral discussion of the results and a final session, which highlighted a preview of an International Jupiter Watch organization, was organized by Dr. C. Russell.

(c) Anticipated Accomplishments: The Proceedings of the Workshop will be published in 1988 as a NASA-Special Publication. It will contain thirty papers - including all of the invited papers given at the Workshop. We expect that it will become the basic scientific rationale for an International Jupiter Watch program that will soon be proposed to NASA.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

The Reduction and Analysis of Photometric Data on Comet Halley

PERFORMING ORGANIZATION

Kitt Peak National Observatory
950 N. Cherry Avenue
Tucson, AZ 85719

INVESTIGATOR'S NAME

Michael J. S. Belton (with U. Fink, P. Wehinger, H. Spinrad, K. Meech other observers)

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Strategy: The discovery that periodic variations in the brightness of Comet Halley were characterized by two unrelated frequencies implies that the nucleus is in a complex state of rotation. It either nutates as a result of the random addition of small torque perturbations accumulated over many perihelion passages, or the jet activity torques are so strong that it precesses wildly at each perihelion passage. To diagnose the state of nuclear rotation we have begun a program to acquire photometric time series of the comet as it recedes from the sun. The intention is to observe the decay of the comet's atmosphere and then, when it is unemcumbered by the light of the coma, follow the light variation of the nucleus itself. The latter will be compared with preperihelion time series and the orientation of the nucleus at the time of Vega and Giotto flybys and an accurate rotational ephemeris constructed.

(b) Accomplishments: We have observed Halley on 38 nights during 1987 and approximately 21 nights in 1988. The comet moved from 5 AU to 8.5 AU during this time. The brightness of the coma was found to rapidly decrease in 1988 as the coma and cometary activity collapses. The magnitude in April 1988 was 19 mag (visual) and it is predicted that the nucleus itself will be the major contributor to the brightness in the 1988/89 season. The 1987 data from KPNO is reduced, and that from the Catalina observatory is about half completed. The detailed reduction of 1988 data is expected to begin at the end of June 1988.

(c) Anticipated Accomplishments: We are in the middle of the data reduction process for the present data set of some 410 CCD frames and expect to have this phase completed by the end of 1988 (we are continuing observations and expect to stimulate a Halley Nucleus Observing campaign on an international level for the 1988/89 season, so new data should be forthcoming, which will also require reduction). The future analysis depends on the availability of some basic tools which we are developing now. One is the application of the CLEAN algorithm (for spectral analysis of the time series data), and the other is a program that simulates the light variations of a model Halley's nucleus. The latter is essentially complete, and work is ongoing regarding the CLEAN program.

N89-16633

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY SPECTROSCOPY

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME	TEL. NO.
Bergstralh, J. T.	(818) 354-2296

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of previous year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. The goal of this task is to acquire physical data on the atmospheres of the outer planets and Titan by means of ground-based spectroscopy, spectrophotometry, and spectral imaging at visible to near-infrared wavelengths (approximately 0.3 to 2.5 microns). These data constrain physical parameters which characterize properties and distribution of aerosols in the atmospheres of these bodies. Work in the coming year will focus primarily on Neptune, to support the upcoming Voyager encounter with that planet. This task includes only data acquisition and reduction; analyses are performed under separate tasks.

b. Reduced spectral imaging of Neptune. The data were analyzed in several ways. Direct inspection of images reveals the distribution of discrete clouds in the atmosphere, which indicate that the global distribution of clouds has changed since earlier imaging. Disk-integrated photometry obtained from the images demonstrates that the diurnal variability at methane-band wavelengths is caused by the presence of discrete clouds; short-term variability is also seen in the rotational light curve, providing evidence for modification of cloud structure on the planet. The center-to-limb brightness profiles of the equatorial region of Neptune were analyzed, which provided constraints on the location, albedos, and optical depths of aerosol scattering layers in the troposphere and lower stratosphere.

c. (1) Three observing runs at Mauna Kea Observatory (University of Hawaii 2.24-meter telescope) to obtain CCD imaging at well-defined spectral bandpasses. These data, when combined with past observations, will provide a continuous series of photometrically calibrated data over a timescale of several years. One of the runs will be specifically requested to coincide with the Voyager encounter time. (2) Continued analyses of older data are also planned. (3) Report results at DPS meeting in Austin, TX.

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N89-16634

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Photometry of Pluto-Charon Mutual Events and Hirayama Family Asteroids

PERFORMING ORGANIZATION

Planetary Science Institute
2030 E. Speedway Blvd.
Tucson, AZ 85719

After 1 August 1988:
Dept. Earth Atmospheric Planetary Science
Massachusetts Institute of Technology
Cambridge, MA 02139

INVESTIGATOR'S NAME

Richard P. Binzel

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Once every 124 years, nature provides earth-bound astronomers with the opportunity to observe occultation and transit phenomena between Pluto and its satellite, Charon. Ground-based observations of these events will allow precise physical parameters for the Pluto-Charon system to be derived which are unlikely to be improved upon until *in situ* spacecraft observations are obtained. The proposed program will continue to support photometry observations from McDonald Observatory, a critical location in an International Pluto Campaign network. Knowledge of the diameters, masses, densities, and compositions derived from these observations will augment our understanding of Pluto's origin and its context within the problem of solar system formation.

A second task will continue to research the evolutionary processes which have occurred in the asteroid belt by measuring the physical properties of specific Hirayama family members. Photoelectric lightcurve observations of Koronis and Themis family members will be used to investigate the individual catastrophic collision events which formed each family. By comparing these properties with results of laboratory and numerical experiments, the outcomes of catastrophic disruptions and collisional evolution may be more precisely determined.

(b) This contract has been funded for eight months. Reduction and analysis of 1987 multi-color photometry has provided individual colors for Pluto and Charon and has shown they have relatively uniform hemispherical distributions (Binzel 1988a). During 1988, observations of 8 additional mutual events have been obtained or attempted.

New lightcurve observations have been obtained for ~20 asteroids in the Koronis and Themis families and also targets of opportunity such as the Galileo flyby target 243 Ida. A preliminary analysis supports the hypothesis (Binzel 1988b) of a recent formation for the Koronis family.

(c) This year, four to six Pluto-Charon mutual events will be observed using the McDonald Observatory 2.1- and 2.7-m telescopes. Events observed in 1989 will be partial transits and occultations involving the southern hemisphere of Pluto and the northern hemisphere of Charon. The McDonald data will be combined with those at other longitudes to allow the best possible solution to be derived for diameters, masses, and densities. These new observations will be combined with existing data to construct a preliminary albedo surface map for one hemisphere of each body.

Observations of 10-15 Hirayama family asteroids will be obtained this year utilizing about 20 nights of 1-m telescope time at McDonald, Kitt Peak, and other observatories. Lightcurve observations of Koronis family asteroids at ecliptic longitudes ~90 degrees away from previous measurements will be used to test whether their spin vectors have a preferential low obliquity alignment, which is evidence for a recent formation. Observations of Themis family asteroids will broaden our understanding of catastrophic disruption events.

d. Publications

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Binzel, R. P. (1988b). "Collisional Evolution in the Eos and Koronis Asteroid Families: Observational and Numerical Results." *Icarus* **73**, 303-313.

N89-16635

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Studies of Asteroids, Comets, and Jupiter's Outer Satellites, NSG-7500

PERFORMING ORGANIZATION

Lowell Observatory

INVESTIGATOR'S NAME

Edward Bowell

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Our work comprises observational, theoretical, and computational research on asteroids, together with a smaller effort concerning the astrometry of comets and Jupiter's satellites JVI through JXIII. Two principal areas of research, centering on astrometry and photometry, are interrelated in their aim to study the overall structure of the asteroid belt and the physical and orbital properties of individual asteroids.

(b) We have measured and published about 2000 accurate photographic positions of asteroids and comets, including a number from the Lowell, Palomar, and Goethe-Link archival plate collections, the last of which was donated to us last winter by Indiana University. CCD astrometry of 36 faint targets was undertaken, including 4 comets; JVI, JVII, JVIII, JIX, JXI, and JXII; and 26 asteroids, most of which are Earth-approachers. We started a deep, bias-correctable asteroid survey (LUKAS), the aim of which is to determine the true spatial distribution of asteroids down to subkilometer diameters, and obtained a series of eight plates at the UK Schmidt telescope that contain images of asteroids as faint as V $\sim$ 22 mag. Analysis of microdensitometric scans of two plates has shown that we can identify about 98% of the asteroid images completely automatically. A review called "Discovery and Follow-up of Asteroids" has been submitted to *Asteroids II.* Orbit files have been updated monthly, and orbits and ephemerides have been distributed to observers on request. We have completed work on a photometric study of Chiron (a paper is in press in *Icarus*), and we have started two CCD photometry tasks to determine rotational characteristics and surface light-scattering properties of asteroids: one on kilometer-size UCAS asteroids, and one on 11 selected main-belt asteroids in support of scale calibration for HST. Work on the so-called H, G magnitude system for asteroids is virtually complete and a manuscript will shortly be submitted to *Icarus.* A paper entitled "Modelling Asteroid Brightness Variations. I. Numerical Methods" has been submitted to *Astronomy and Astrophysics*, and a review on "Application of Photometric Models to Asteroids" is in preparation for *Asteroids II.* Good progress has been made on exploring the idea that the opposition spike, seen in the phase curves of icy satellites and some high-albedo asteroids, results from an admixture of transparent crystalline material.

(c) Our main astrometric effort will concern LUKAS, which we hope to get up to a "production" rate of two or three fields per year. We anticipate generating one- and two-month orbital arcs for perhaps 2000 small asteroids. Related work needs to be done on the problem of linking images from one plate to another, and this should result in a paper called "A Generalization of Väisälä's Method of Apsidal Orbit Determination". To accommodate the deep survey, our other photographic astrometry programs will be reduced in scope; but CCD astrometry of faint asteroids, Jupiter satellites, and comets should continue unabated, as should CCD photometry of small UCAS asteroids and HST scale-calibration asteroids. The work on lightcurve interpretation should progress to the completion of a paper entitled "Modelling Asteroid Brightness Variations. II. On the Uninterpretability of Phase Curves and Lightcurves"; and a third paper will be started concerning the displacement of an asteroid's photocenter with rotation and phase angle and the modelling of lightcurves of asteroids occulted by the Moon. We will also explore incorporating the opposition spike in a three-parameter version of the H, G magnitude system.

(d) Summary Bibliography

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N89-16636

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Evolution of Large-Scale Plasma Structures in Comets: Kinematics and Physics

PERFORMING ORGANIZATION

Laboratory for Atmospheric and Space Physics
University of Colorado
Boulder, CO 80309-0392

INVESTIGATOR'S NAME

John C. Brandt

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Strategy: Disconnection Events or DEs are the dramatic part of the periodic morphology involving the separation of the entire plasma tail from the head region of the comet and the growth of a new plasma. The coordinated observations of comet Halley recorded approximately 30 DEs during the 7 months of plasma activity; 19 of these are obvious. We approach the plasma physics of these events via a detailed, kinematic investigation of specific DEs and the solar-wind environment associated with it. As the detailed investigations are completed, we should be able to answer the question of a single or multiple mechanism(s) for DEs and determine which mechanism(s) are important. At present, the mechanism of sunward magnetic reconnection caused by interplanetary sector boundary crossing is consistent with the data available.

(b) Accomplishments: Note that this research activity is scheduled to begin on October 1, 1988. Activities underway before this date are: (1) assembling the Image Archive for the Large-Scale Phenomena Network of the International Halley Watch at Boulder, CO. Logistical arrangements are complete and the images are arriving at a steady rate; (2) Reviews of the field have been presented at Solar Wind VI and COSPAR; a major review is in press (Brandt 1988); (3) an analysis of the major DE of January 9-11, 1986 is underway. Initial results indicate consistency with the sector boundary hypothesis.

(c) Anticipated Accomplishments: During the first year of this program, we plan to complete the archive facility at Boulder and fully analyze two DEs. These have been tentatively selected as the DEs of December 31, 1985 and April 15, 1986.

d. Publications

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N89-16637

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

INFRARED OBSERVATIONS OF SMALL SOLAR-SYSTEM BODIES

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME | TEL. NO.

Brown, R. H. (818) 354-1799

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year, c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) OBJECTIVES

(*TASK 1*): To measure eclipse diasppearance and reappearance curves for the Galilean satellites Europa and Ganymede to determine the penetration scale length for sunlight and thus to detemine the extent to which the solid-state greenhouse effect is operating on these two bodies. I will use the IRTF at Mauna Kea Observatory to obtain flux measurements at narrow-band wavelengths of 8.7 and 20 μm during several eclipse disappearances and reappearances of Europa and Ganymede. The measurements wil be interpreted using solid-state greenhouse models developed by D. Matson and me.

(*TASK 2*): To measure the reflectance spectra of the icy satellites of Jupiter, Saturn, Uranus and Neptune in the region 2.0 to 2.5 μm using the 32-element InSb photodiode array spectrometer of the IRTF at Mauna Kea Observatory. The specific objective is to search for methane, ammonia and carbon monoxide ices and clathrates on icy surfaces in the outer solar system. The data will allow upper limits to be placed on the amount of these chemical species present. Specific targets are Enceladus, Ariel, Titania, and Triton.

b) PROGRESS: A major accomplishment during last year is the recognition of and modeling of the solid-state greenhouse effect for icy satellites. Recent observations of eclipse reappearances suggest that this effect may in fact be observed on Europa and Ganymede. Also the PI has obtained important new data on Europa and Enceladus. Evidence for the transient presence of a volatile, perhaps $NH_3 \cdot OH$, on Europa has been obtained; A paper is in press in *Icarus*. Newly obtained spectra of Enceladus suggest that it does not at present have ammonia or methane in detectable quantities on its surface. A paper is in preparation.

c) PROPOSED WORK: First, it is proposed to obtain additional observations of eclipse reappearances and disappearances of Europa and Ganymede, and to extend our existing solid-state greenhouse models to include a surface which is stratified in density. We will use the data and the models to get an estimate of the extent of solid-state greenhousing on Ganymede and Europa. Second, it is proposed to observe Ariel, Dione, Rhea and Titania in the search for volatile surface constituents.

d) SUMMARY BIBLIOGRAPY:

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Matson, D. L. and R. H. Brown (1988). Solid-state greenhouses and their implications for icy satellites. *Icarus*, in press.

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N89-16638

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Arecibo S-Band Radar Program

PERFORMING ORGANIZATION

National Astronomy and Ionosphere Center
Space Sciences Building
Cornell University
Ithaca, N.Y. 14853

INVESTIGATOR'S NAME

Donald B. Campbell

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a)General Objectives: The high powered 12.6cm wavelength radar on the 1000-ft Arecibo reflector is utilized for a number of solar system studies. Chief among these are: 1) Surface reflectivity mapping of Venus, Mercury and the Moon. Resolutions achievable on Venus are less than 1.5km over some areas, for Mercury about 30km and for the Moon 200m at present. 2) High time resolution ranging measurements to the surfaces of the terrestrial planets. These measurements are used to obtain profiles and scattering parameters in the equatorial region. They can also be used to test relativistic and gravitational theories by monitoring the rate of advance of the perihelion of the orbit of Mercury and placing limits on the stability of the gravitational "constant". 3) Measurements of the orbital parameters, figure, spin vector and surface properties of asteroids and comets. 4) Observations of the Galilean Satellites of Jupiter and the satellites of Mars, Phobos and Diemos.

b)Past Twelve Months: The Galilean Satellites of Jupiter were re-observed with the 12.6cm radar for the first time since 1981. Much more accurate measurements of the scattering properties of the three icy satellites were obtained that generally confirmed previous observations. Unambiguous measurements of the cross section and circular polarizations ratio of Io were also obtained for the first time. The radar scattering properties of four mainbelt asteroids and one near-earth asteroid were studied and the turbulence spectrum of the solar wind within 20 solar radii of the Sun was measured by examining propagation effects on echoes reflected from Venus when it was close to superior conjunction. Late May saw a commencement of a new set of mapping observations of Venus. Papers covering observations of Comets IRAS-Araki-Alcock and Halley, measurements of turbulence in the solar wind and studies of the surface of Venus were submitted for publication.

c)Next Twelve Months: A heavier than normal observing schedule is planned for the next eight months.Mapping observations of Venus will continue until early July, Mars' observations aimed at delineating areas of high surface roughness will commence in August and an attempt will be made to detect the satellites of Mars, Phobos and Diemos, in September.Approximately twenty observing sessions will be devoted to measurements of the scattering properties of the Galilean Satellites at both 70cm and 12.6cm wavelengths.Detailed topographic measurements of Aphrodite Terra on Venus will be made in late summer and fall aimed at attempting to verify the suggestion that this region contains numerous cross strike discontinuities and the program of high resolution (<100m) imaging of the moon will recommence in early 1989.A number of asteroids will be observed including the small earth approaching objects, 433 Eros,1685 Toro and 1980 PA.

d. Publications

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Stofan, E.R., Head, J.W., Campbell, D.B., Zisk, S.H., Bogomolov, A.F., Rzhiga, O.N., Basilevsky, A.T. and Armand, N., Geology of a Rift Zone on Venus: Beta Regio and Devana Chasma, submitted to the GSA Bulletin.

N89-16639

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY ASTRONOMY (NASW-4266)

PERFORMING ORGANIZATION

Planetary Science Institute
2030 East Speedway, Suite 201
Tucson, Arizona 85719

INVESTIGATOR'S NAME

Dr. Clark R. Chapman

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: The above-referenced Planetary Astronomy contract supports five senior researchers at the Planetary Science Institute (Drs. Campins, Chapman, Davis, Hartmann, and Weidenschilling) with some involvement of other staff members. The goal is to use a variety of observational techniques and instruments to reduce, interpret, and synthesize groundbased astronomical data concerning the comets, asteroids, and other small bodies of the solar system in order to study the compositions, physical characteristics, population properties, and evolution of these bodies.

b. Accomplishments: This year's research has involved five distinct efforts. Chapman has studied asteroids, with emphasis on synthesizing groundbased databases to determine surface mineralogies and population characteristics; many new results on taxonomy, size-distributions, and asteroid family traits have been obtained. Weidenschilling, Davis, and Chapman have been analyzing their 5-year lightcurve database on large, rapidly-rotating asteroids (a collaborative paper with Drummond is in press), and are involved in observations to fill in gaps in ecliptic longitude coverage. Hartmann has studied asteroids, Trojans, and comets using colorimetric, photometric, and spectrophotometric techniques and has clarified relationships among the various classes of outer-solar-system bodies and some Earth-approachers. Davis and Campins are renewing our earlier efforts to detect and study vulcanoids (hypothesized small bodies interior to Mercury's orbit) using more sensitive daytime IR techniques. Campins has used detector arrays for IR photometry and dynamical analysis of images of comets to study cometary dust. Chapman, Campins and others have performed a variety of programmatic tasks, as well, including Chapman's past chairmanship of the Planetary Astronomy MDWG.

c. Anticipated Accomplishments: We will continue in the directions mentioned earlier, with emphasis on interpretation and synthesis to follow up on the Asteroids II Meeting. A variety of observations will continue at Mauna Kea, Kitt Peak, Mt. Lemmon and elsewhere. Among the objects or classes of objects to be observed are Comets Brorsen-Metcalf and Schwasmann-Wachmann 1, 2060 Chiron, other Trojans, Hildas, and rapid rotators, and (perhaps) vulcanoids. Programmatic activities will continue at a reduced level.

d. Summary Bibliography (attached)

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N89-16640

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Imaging and Spectroscopy of Comet P/Halley

PERFORMING ORGANIZATION

Atmospheric and Environmental Research, Inc.
840 Memorial Drive, Cambridge, MA 02139

INVESTIGATOR'S NAME

Michael R. Combi

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. The goals of this investigation are the analysis of a large set of high-resolution echelle/reticon spectra, and the reduction and analysis of a set of IAU narrow-band-filtered CCD images of comet Halley taken during the pre-perihelion period at Oak Ridge Observatory (CFA/SAO) by Dr. R. E. McCrosky. The scientific objectives associated with these goals are the determination of the spatial distributions of several important radicals, atoms and ions in the coma. These include C_2, CN, C_3, H_2O^+ and CO^+ from the image data and the $O(^1D)$ to NH_2 ratio from the spectral data. The analysis of the neutral species distributions with our Monte Carlo models, will aid in the understanding of their production and decay mechanisms as well as serve as an important indicator of the physical conditions in the inner coma. The spatial distributions of the ions will serve as a guide to constrain the complex models necessary for understanding the interaction of the solar wind and the cometary ions.

b. Work during this past year has been devoted largely to the reduction of the standard star photometry for the CCD image data set, as well as the re-flat-fielding of a number of the comet images. We are pleased to report that despite a number of setbacks and the small effort devoted to this work ($2\ 1/2$ months for the PI and a generous share of completely unsupported time by Dr. McCrosky) that this portion of the work has been successfully completed.

c. The goals for the upcoming final year of this project (under a new project number) are to complete the calibration of the CCD image data for inclusion in the IHW archive, to analyze a select portion of the neutral radical images with our Monte Carlo models, and to present the results of the 6300/ region spectra as a guide to low-resolution spectral observers in order to yield the unambiguous separation of the contributions of cometary $O(^1D)$, airglow $O(^1D)$, and the numerous NH_2 lines in that region of the spectrum.

d. CCD Images and High Resolution Spectra of Comet P/Halley, M.R. Combi and R.E. McCrosky, 1986, ESA SP-250, 393.
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
NEAR-INFRARED OBSERVATIONS OF VENUS

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME	TEL. NO.
Crisp, D.	(818) 393-7971

DESCRIPTION *(a. Brief statement on strategy of investigation. b. Progress and accomplishments of prior year. c. What will be accomplished this year, as well as how and why, and d. Summary bibliography)*

a. Ground-based near-infrared observations of the Venus night side reveal anomalous bright features at wavelengths near 1.7 and 2.3 microns (Allen and Crawford, 1984; Allen, 1987). These features are thought to be formed as thermal radiation from the hot lower atmosphere leaks through holes in the Middle and/or Lower sulfuric acid cloud decks. Because these holes allow radiation to escape from deep in the troposphere, they provide an opportunity to significantly improve our understanding of the composition, thermal structure, and dynamics of this region of the Venus atmosphere. New near-infrared observations of the Venus night side are needed to address these questions.

b. During the first year of this program, we requested and received observing time at six sites and organized a highly-skilled team: KPNO 1.3 m, Probst (5/17-23, 6/24-30); TMO 24-inch, Baines, Crisp (5/17-30), McKelvey (6/21-30); Palomar 200-inch, Hester, Beichman, Crisp (5/28-6/2), Soiffer, Mathews (6/24-30); Univ HI 88-inch, Sinton, Ragent, Allen (5/28-30); UKRT, Lugton (5/24-27); CHFT, Malliard (4/24-29).

This wide array of sites should allow us to collect the data needed to meet all of our proposed objectives. J. Malliard used the CHFT FTS to obtain high resolution spectra of the Venus night side. We are currently collecting our first images of Venus from Kitt Peak and Table Mountain. The state-of-the-art infrared array detectors that are being used at these sites are allowing us to collect hundreds of high-quality images during each observing day. These images show the expected bright features, but we have not yet begun to track these features. We anticipate submitting one or more publications that summarize the results of these observations before the end of FY 88.

c. High resolution spectroscopic and imaging observations of the Venus night side will be used to estimate the column abundances of CO, HF, HCL, and other important trace gases which have absorption features at wavelengths near 1.7 and 2.3 microns in the Venus night-side troposphere. Images of the Venus night side will be processed to 1) better constrain the altitude range where the bright features are produced, 2) track horizontal winds at these levels, and 3) determine the fractional area covered by bright features to assess the impact of the these leaks on the atmospheric Greenhouse mechanism. We will also collaborate with members of the Galileo Project to assess the feasibility of carrying our similar observations during the Venus flyby.

d. Allen, D. ''The Dark Side of Venus,'' *Icarus* **69**, 221-229, 1987. Allen, D. and J.W. Crawford, ''Cloud Structure on the Dark Side of Venus,'' *Nature* 307, 222-224, 1984.

N89-16642

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Research in Planetary Astronomy and Operation of the Mauna Kea Observatory

PERFORMING ORGANIZATION

NASA Ames Research Center — Formerly the PI was at the Institute for Astronomy University of Hawaii, Honolulu, where much of this work was performed

INVESTIGATOR'S NAME

Dr. Dale P. Cruikshank

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

Strategy: Spectroscopic studies with ground-based telescopes at low resolution can give compositional information on the surfaces and atmospheres of planets, satellites, asteroids, and comets. Solid state absorptions in ices and minerals are measurable by the low-resolution spectrophotometric technique. This program includes spectroscopy of distant comets, asteroids of particular interest in various contexts (planet crossers, outer main belt, trojans, etc.), Pluto and Charon, and planetary satellites of particular interest (Iapetus, Io, Uranian satellites, etc.). In the case of planets, satellites, and comets, emphasis is placed on volatiles (ices and organics), while for asteroids the stress is on mineralogy and the connection with the meteorites.

Accomplishments: **Triton:** New spectra show that the IR signature of the satellite has changed since 1980, in that the methane bands are significantly weaker. Spectral evidence for the presence of molecular nitrogen remains convincing. Also, the brightness of Triton throughout its orbital cycle was measured to higher precision than before and found to be constant to better than 0.02 mag. **Asteroids:** Suggestive spectral evidence was found for the presence of the C-H stretching mode band in diffuse reflection on asteroid 130 Elektra. The planet-crossing asteroid 3551 (1983RD) was found to have a Vesta-like spectrum, and may be a piece of the parent body of the (differentiated) eucritic meteorites. Asteroid 2060 Chiron was found to exhibit an anomalous brightening (by 0.6 mag) indicating some kind of comet-like activity at 12 AU from the sun. **Io:** Spectra were taken in eclipse to study sulfur dioxide in the volcanic plumes. **Comets:** VJHK photometry was obtained of Comet P/Halley at distance ~8 AU showing different colors from those observed before and during perihelion. Several other comets were observed with the same technique.

Anticipated Accomplishments: New data will be obtained for Triton at shorter wavelengths to test for other hydrocarbons (e.g. ethylene) and to discriminate between gas and ice of methane. New VJHK photometry and near IR spectra of comets will be obtained to search for diagnostic spectral features in 2-um region. Asteroids will be observed in study of the connection to certain meteorite types and in pursuit of the problem of the origin of the ordinary chondrites. Additional data will be obtained on the organic band in asteroids and the dark hemisphere of Iapetus. New spectra of Io for the study of the volcanoes will be obtained. Collaboration with laboratory scientists at NASA Ames will continue in connection with these planetary problems.

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H. B. Hammel, C. M. Telesco, H. Campins, R. Decher, A. D. Storrs, and D. P. Cruikshank. "Albedo Maps of Comets P/Halley and P/Giacobini-Zinner." **Astron. Astrophys. 187**, 665-668, 1987.

M. W. Buie, D. P. Cruikshank, L. A. Lebofsky, and E. F. Tedesco. "Water Frost on Charon." **Nature 329**, 522-523, 1987.

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N89-16643

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Spectroscopic Planetary Detection

PERFORMING ORGANIZATION

Planetary Systems Branch, Code 693
Goddard Space Flight Center, Greenbelt MD 20771

INVESTIGATOR'S NAME

Drake Deming

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: One of the most promising methods for the detection of extra-solar planets is the spectroscopic method, where a small Doppler shift (~ 10 meters/sec) in the spectrum of the parent star reveals the presence of planetary companions. However, solar-type stars may show spurious Doppler shifts due to surface activity. If these effects are periodic, as is the solar activity cycle, then they may masquerade as planetary companions. The goal of this investigation is to determine whether the solar cycle affects the Doppler stability of integrated sunlight. Observations of integrated sunlight are made in the near infrared (~ 2 μm), using the Kitt Peak McMath Fourier transform spectrometer, with an N_2O gas absorption cell for calibration. We currently achieve an accuracy of ~ 5 meters/sec. Solar rotation velocities vary by ±2000 meters/sec across the solar disk, and imperfect optical integration of these velocities is our principal source of error.

b. Accomplishments: We have been monitoring the apparent velocity of integrated sunlight since 1983. We initially saw a decrease of ~ 30 meters/sec in the integrated light velocity from 1983 through 1985, but in 1987-88 the integrated light velocity returned to its 1983 level. It is too early to say whether these changes are solar-cycle related. Although the FTS, unlike a slit spectrograph, has a large field of view, we are always looking for ways to improve our optical integration of the solar disk. We recently made an improvement in the method used to optically collimate the FTS, and this has reduced our error level, eliminating some systematic effects seen earlier.

c. Anticipated accomplishments: We will continue to monitor the apparent velocity of integrated sunlight. When solar maximum has passed (>1991), we should know whether the changes seen earlier in integrated light velocity are periodic with the solar cycle, and thus to what degree solar-type stars can be expected to show spurious Doppler signals which might interfere with spectroscopic planetary detection.

d. Publications: "On the Apparent Velocity of Integrated Sunlight," D. Deming, F. Espenak, D. E. Jennings, J. W. Brault and J. Wagner 1987, Ap.J. **316**, 771-787.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Speckle Interferometry of Asteroids

PERFORMING ORGANIZATION
Steward Observatory
University of Arizona
Tucson, Arizona 85721

INVESTIGATOR'S NAME
Jack Drummond

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: By studying the image two-dimensional power spectra or autocorrelations projected by an asteroid as it rotates, it is possible to locate its rotational pole and derive its three axes dimensions through speckle interferometry under certain assumptions of uniform, geometric scattering, and triaxial ellipsoid shape. However, in cases where images can be reconstructed, the need for making the assumptions is obviated. Furthermore, the ultimate goal for speckle interferometry of image reconstruction will lead to mapping albedo features (if they exist) as impact areas or geological units.

b. Accomplishments: The first glimpses of the surface of an asteroid have been obtained from images of 4 Vesta reconstructed from speckle interferometric observations. These images reveal that Vesta is quite Moon-like in having large hemispheric-scale albedo features. All of its lightcurves can be produced from a simple model developed from the images. Although undoubtedly more intricate than the model, Vesta's lightcurves can be matched by a model with three dark and four bright 'spots'. The dark areas so dominate one hemisphere that a lightcurve minimum occurs when the maximum cross-section area is visible. The triaxial ellipsoid shape derived for Vesta is not consistent with the notion that the asteroid has an equilibrium shape in spite of its having apparently been differentiated.

c. Future goals: Ten images of Vesta were reconstructed from data obtained with the PAPA detector in 1983. Some 65 observations were made with the MAMA detector in 1986, and have been reduced to power spectra and phases. The immediate goal of the program at Steward Observatry is to identify the optimal image reconstruction algorithm, produce better images of Vesta from the newer data, to verify the first set of images, and to make similar observations and images of other asteroids. However, further progress toward this goal must await funding, since the speckle program at Steward Observatory has no federal, state, or local financial support for astronomy.

d. Publications:

Drummond, J.D., Eckart, A., and Hege, E.K. (1988). Speckle interferometry of asteroids. IV. Reconstructed images of 4 Vesta. *Icarus* **73**, 1-14.

Drummond, J.D., Weidenschilling, S.J., Chapman, C.R., and Davis, D.R. (1988). Photometric geodesy of main belt asteroids. II. Analysis of lightcurves for poles, periods, and shapes. *Icarus*, In press.

Gehrels, T., Drummond, J.D., and Levenson, N.A. (1987). The absence of satellites of asteroids. *Icarus* **70**, 257-263.

Taylor, R. C., Birch, P.V., Drummond, J.D., Pospieszalska-Surdej, A., and Surdej, J. (1987). Asteroid 532 Herculina: lightcurves, pole orientation and a model. *Icarus* **69**, 354-369.

N89-16645

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Portable High-Speed Photometry Systems for Observing Occultations

PERFORMING ORGANIZATION

Department of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

INVESTIGATOR'S NAME

James L. Elliot

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. **Strategy**: Because of their high spatial resolution, stellar occultations have proven extremely effective for learning about planetary upper atmospheres, asteroids, and planetary rings. Our ring orbit studies for Uranus have been particularly fruitful because we have been able -- through occultations -- to obtain data of high spatial resolution (~2km) at the rate of 1-2 times per year. Our occultation program at M.I.T. involves (i) identifying the scientific questions that can be answered by occultation events, (ii) predicting the zone of visibility for the useful events, (iii) maintaining and improving a set of portable high-speed photometric systems, (iv) obtaining the observations, and (v) reducing the data and interpreting the results.

b. **Accomplishments**: Our accomplishments during the past year include: (i) a comprehensive analysis of stellar occultation data to obtain an oblateness for Uranus at the 10 μbar level of 0.0193 ± 0.0010, a value consistent with the planet being in hydrostatic equilibrium and undergoing rotation at the period found by Voyager; (ii) establishing an upper limit of 0.004 km on the equivalent depth of 1986U1R from 2.2 μm occultation data, which implies that this ring—unlike most other Uranian rings—is composed of micron-sized particles; (iii) the discovery of low-amplitude waves on the edges of the epsilon ring of Uranus; and (iv) the acquisition of several hundred CCD "strip scans," obtained over a period of 6 weeks at Mauna Kea for the purpose of generating a prediction for the stellar occultation by Pluto that occurred on June 9, 1988.

c. **Anticipated Accomplishments**: We are now analyzing the CCD strip scans, and, from the observed "wobble" of the center of light of the Pluto-Charon system with respect to its center of mass, we expect to establish the relative masses of the two bodies. Also we shall be continuing our analyses of the "four-day" occultation by Uranus in order to learn more about the "kinks" that we have found on the edges of the delta ring. From our multiple observations from Mauna Kea and Siding Spring, we hope to establish whether the kinks on the profile edges are caused by a wave on the edge of the ring or are a manifestation of a spiral density wave within the ring.

d. Publications

Elliot, J.L.; Glass, I.S.; and French, R.G.: The Occultation of KME 17 by Uranus and its Rings. *Icarus* **71**, 91-102 (1987).

French, R.G.; Elliot, J.L.; French, L.M.; Kangas, J.A.; Meech, K.J.; and Ressler, M.E.: Uranian Ring Orbits from Earth-Based and Voyager Occultation Observations. *Icarus* **73**, 349-378 (1988).

French, R.G.; Jones, T.J.; and Hyland, A.R.: The 1 May 1982 Stellar Occultation by Uranus and the Rings: Observations from Mount Stromlo Observatory. *Icarus* **69**, 499-505 (1987).

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Millis, R.L.; Wasserman, L.H.; and French, R.G.: Observations of the 22 April 1982 Stellar Occultation by Uranus and the Rings. *Icarus* **60**, 176-184 (1987).

N89-16646

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Spectroscopy

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Uwe Fink 602-621-2736

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: The main goal of our research is CCD spectroscopic and imaging studies of the solar system in support of spacecraft investigations. Our studies include the physical behavior of comets, the atmospheres of the gaseous planets, and the solid surfaces of satellites and asteroids.

b. Accomplishments: Our major observing program consisted of ~50 nights of photometry of Comet P/Halley in order to resolve the controversy over this comet's rotation period. This data is presently being analyzed by Dr. Mike Belton of KPNO, who collaborated in this effort. Additional observing projects included the spectroscopic occultation of Charon by Pluto, reflection spectroscopy of Mercury (in collaboration with Dr. Neukum and S. Engel from Germany) and a spectrum of the Uranian satellite Oberon. Our Mercury data does not corroborate the Fe^{++} absorption feature reported by McCord and Clark at 8800 A but instead potentially shows a weaker feature at longer wavelengths. This position is in much closer accord with expectations for Mercury since a band center near 8800 A implies too little Fe^{++} on Mercury, especially if band shifts with temperature are considered. The Pluto project proved that the deep methane absorptions visible in their combined spectra are due solely to Pluto with Charon showing a flat and featureless spectrum. It appears that if Charon ever contained a substantial methane component, the satellite's low surface gravity could not hold it and the methane evaporated and escaped.

c. Anticipated Accomplishments: The analysis of the Mercury data needs to be completed and submitted for publication. We are presently in the midst of reducing and analyzing our spectroscopy and imaging data of comet P/Halley. We have extracted spectra for the whole apparition and have emission profiles for C_2, CN, NH_2 [OI], and H_2O^+ and the dust continuum for 1985 Dec. and 1986 Jan., March and April. Our goal is to determine the spatial distribution and production rates for all of the above species over the range of heliocentric distances provided by the P/Halley apparition. The production rate ratios, compared to H_2O, can tell us the relative cometary abundances of the various species. Their behavior with heliocentric distance can yield clues on the structure of the outer layers of a comet. We have made a good start on this but because of the time-consuming nature of this analysis considerable future work remains.

d. Publications

U. Fink, M. DiSanti, A. Schultz, "The spectral development of Comet P/Halley from 1985 August to 1986 June," *Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, ESA SP-250*, III, (Jan. 1987).

M. W. Buie and U. Fink, "Methane absorption variations in the spectrum of Pluto," *Icarus*, 70, 483-498 (1987).

U. Fink and M. DiSanti, "The separate spectra of Pluto and its satellite Charon," *Astron. J.*, 95, 229-236 (1987).

R. Marcialis and U. Fink, "Spectrophotometry of Oberon," 19th Annual DPS/AAS meeting, Pasadena, California, Nov 10-13, *BAAS*, 19, 819 (1987).

U. Fink and M. A. DiSanti, "The separate spectra of Pluto and its satellite Charon," 19th Annual DPS/AAS meeting, Pasadena, California, Nov 10-13, *BAAS*, 19, 859 (1987).

S. Engel, G. Neukum, U. Fink and A. Schultz, "preliminary results of CCD spectroscopy," 19th Annual DPS/AAS meeting, Pasadena, California, Nov 10-13, *BAAS*, 19, 863 (1987).

A. Schultz, U. Fink and M. DiSanti, "H_2O^+ 0, 8, 0 emission from comet Halley," 19th Annual DPS/AAS meeting, Pasadena, California, Nov 10-13, *BAAS*, 19, 886 (1987).

M. DiSanti, U. Fink and A. Schultz, "Spectroscopy and spatial profiles of the [OI] 6300 A emission from comet Halley," 19th Annual DPS/AAS meeting, Pasadena, California, Nov 10-13, *BAAS*, 19, 886 (1987).

N89-16647

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

CCD Scanning for Comets and Asteroids

PERFORMING ORGANIZATION
Lunar and Planetary Laboratory
Space Sciences Building
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Tom Gehrels

a. **Strategy:** Some populations of objects in the solar system are still poorly known, and the long-range goal of this program is to improve that situation. For instance, the statistics of Trojan asteroids are uncertain, while our previous surveying indicates there is an appreciable systematic difference between the L-4 and L-5 regions, which is hard to explain. We are developing for this goal a new technique of sky surveillance, namely scanning with CCD. With its quantum efficiency and wavelength range greater than that of photographic plates, the CCD should be especially valuable for fast-moving objects such as near-Earth asteroids.

b. **Accomplishments**: A 320 x 512 pixel CCD has been in operation since 1983 on a telescope that is dedicated during the dark half of each month to sky surveillance, that is the Spacewatch Telescope which is the 91-cm Newtonian reflector of the Steward Observatory on Kitt Peak. The preparations included extensive computer programming for automatic detection of moving objects and for processing in real time. With exposure time of 1 minute, the visual limiting magnitude is 19.6 at the 6-sigma detection level.

New asteroids are readily found, but we have chosen to follow with astrometry only a few of them that are of special interest: a Trojan, a Hilda-type, a 2:3 resonance asteroid, and a few Hungarias.

The system was found to be of special value for astrometry. The telescope drive is turned off at a selected distance west of the object and the scan is continued such that the number of astrometric standards is optimized. Because the drive is off, the effects of refraction practically vanish. It is in principle a transit technique, but that can be applied anywhere in the sky and not merely in the meridian. The precision turns out to be better, by nearly a factor of 2, than what is usually done for asteroids and comets. Astrometry has been done for a large number of objects, particularly also for new discoveries of other astronomers and in order to faciliate radar observations. The results have been regularly published in the Minor Planet Circulars and comet recoveries in the I.A.U. Circulars.

c. **Anticipated Accomplishments**: We are presently installing a 2048 x 2048 CCD with pixel size of 27 microns at the f/5 focus of the Spacewatch Telescope. It will gradually come online in 1989 for automatic data processing, but while this is taking place we shall use the system in tests of CCD scanning techniques on a variety of populations in the solar system.

d. Publications:

Gehrels, T., Drummond, J. D., and Levenson, N. A.: The Absence of Satellites of Asteroids. Icarus **70**, 257-263, 1987.

Gehrels, T., Landau, R., and Coyne, G. V.: Mercury: Wavelength and Longitude Dependence of Polarization, Icarus **71**, 386-396, 1987.

The Minor Planet Circulars give the monthly reports on comet and asteroid observations made by the Spacewatch Telescope; several I.A.U. Circulars have reported comet recoveries.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

High-Resolution Imaging of Solar System Objects

PERFORMING ORGANIZATION

Earth and Space Sciences Division
Jet Propulsion Laboratory, Caltech
Pasadena, CA 91109

INVESTIGATOR'S NAME

Bruce A. Goldberg

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: The strategy of this investigation has been to develop new high-resolution imaging capabilities and to apply them to extended observing programs. These programs have included Io's neutral sodium cloud and comets. The Io observing program was carried out at Table Mountain Observatory (1976-81); providing a framework for interpreting Voyager measurements of the Io torus, and serving as an important reference for studying asymmetries and time variabilities in the Jovian magnetosphere. Comet observations made with the 3.6m Canada-France-Hawaii Telescope and 1.6m AMOS telescope (1984-87) provide the basis for studying early coma development in Halley, the kinematics of its nucleus, and the internal and external structure of the nucleus to the extent that it can be inferred from the dust and gas distributions in its vicinity. Images of GZ from the ICE encounter period form the basis for unique comparisons with in situ magnetic field and dust impact measurements to determine the ion tail and dust coma structure, respectively.

b. Accomplishments: New capabilities for solar system imaging observations were established at AMOS. Representative CFHT comet images remained on display at the National Academy of Sciences. The Io sodium cloud movie remained on display at the National Air and Space Museum. Processing, analysis, and publication of comet data continued. The collaborative sodium cloud modelling with W. H. Smyth of AER was concluded. An image based on the comparison of ICE magnetic field data with CFHT imaging data appeared on the cover of Comet Encounter, a book published by the AGU.

c. Anticipated Accomplishments: Conclusion of the analysis and archiving of the CFHT comet data set and the Table Mountain sodium cloud data set. Continuation of comet observations at AMOS and initiation of new observing programs which will emphasize initially the study of Martian dust storm development.

d. Publications:

Goldberg, B. A. et al. 1988, cover photograph and supporting explanation for Comet Encounter, A. J. Dessler, Editor, American Geophysical Union.

Goldberg, B. A. et al. 1986, "High-Resolution Imaging Studies of the Near-Nucleus Regions of Comets", Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, 27-31 October, ESA SP-250 (December 1986), pp. 153-156.

Slavin, J. A., Goldberg, B. A. et al. 1986, "The Structure of a Cometary Type I Tail: Ground-Based and ICE Observations of p/Giacobini-Zinner", Geophys. Res. Lett. 13, No. 11, pp. 1085-1088.

Slavin, J. A., Goldberg, B. A. et al. 1986, "The P/Giacobini-Zinner Magnetotail", Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet 27-31 October, ESA SP-250 (December 1986), pp. 81-87.

N89-16649

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Planetary Astronomy: Rings, Satellites, and Asteroids

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, Arizona 85719

INVESTIGATOR'S NAME

Richard Greenberg

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy: Studies of planetary rings focus on the dynamical processes that govern astronomically observable ring properties and structure. These investigations thus help reveal properties of the rings as well as probe the gravity fields of the planets. Satellite studies involve interpretation of orbital motion to extract information regarding the gravity fields of the outer planets and the physical properties of the satellites themselves. Asteroid lightcurve work is designed to investigate the large-scale shapes of the asteroids, as well as to reveal anomalous features such as major topography, possible satellites, or albedo variations.

b) Progress: Work on the nature of viscous transport in planetary rings, emphasizing the role of individual particles' physical properties, has yielded a method for estimating both angular momentum and mass transport given an optical-thickness gradient. This result offers the prospect of ringlet instability, which may explain the square-profile ringlets in Saturn's C Ring. Thermal and reflected lightcurves of 532 Herculina have been interpreted to show that albedo variations cannot be the primary cause of variations. A lightcurve simulation has been developed to model complex asteroidal figures. Bamberga was observed during the December occultation as part of the joint LPL-Lowell program.

c) Proposed Research: The lightcurve simulation will be applied to modelling various asteroids with anomalous sets of data. Correlation will be made with infrared lightcurves. Results on viscosity will continue to be applied to Saturn's ring and then to models of Neptunian ring arcs and Uranian rings, and Saturnian ring structure. Uranian ring occultations will be studied for evidence of local swarms of small bodies.

d) Summary Bibliography: 2 papers, 5 abstracts of presentations.

Publications by Richard Greenberg (Supported by NASA Planetary Astronomy)

Greenberg, R.: Particle Properties and the Large-scale Structure of Planetary Rings. Icarus, in press, 1988.

Lebofsky, L.A., et al.: Infrared Lightcurves of Asteroids 532 Herculina and 45 Eugenia: Proof of the absence of Significant Albedo Markings, Icarus, in press, 1988.

Millis, R.L., et al.: Observations of the 8 December 1987 Occultation by 324 Bamberga, at "Asteroids II" conference, Tucson, March, 1988.

Drummond, J., et al.: The Mysterious Case of 532 Herculina, at "Asteroids II" conference, Tucson, March, 1988.

Greenberg, R.: Particle Properties and the Structure of Planetary Rings. AAS/DPS Meeting. Bull. Amer. Astron. Soc. **19**, 892, 1987.

Greenberg, R.: Viscosity of Planetary Rings. AAS/Div. Dyn. Astron. Meeting. Bull. Amer. Astron. Soc. **19**, 913, 1987.

Greenberg, R.: Viscosity and the Physical Properties of Particles, invited presentation at workshop "Kinetic Theories for Planetary Rings", Cornell Univ., 1987.

N89-16650

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

SUBMILLIMETER HETERODYNE RECEIVER FOR THE CSO TELESCOPE

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME

Gulkis, S.

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. **Strategy:** This task is to build a cryogenically cooled 620-700 GHz astronomical receiver that will be used as a facility instrument at the CalTech Submillimeter Observatory on Mauna Kea, Hawaii. The receiver will have applications as a very high resolution spectrometer to investigate spectral lines in planetary and satellite atmospheres, and comets. The receiver will also be used to make continuum measurements of planets, satellites, and asteroids.

b. **Accomplishments:** During FY88, a scale model (200 GHz) SIS mixer radiometer was built and integrated into a cryostat designed for use on the CSO telescope. This system will serve as a model to guide the work on the higher frequency mixer. A solid state local oscillator source that covers two bands in the 600-700 GHz has been developed under contract to JPL and will be delivered before the end of the year. Work has continued on the SIS materials needed for the 620-700 GHz mixer. Test hardware has been developed which allow the I-V curves for SIS material to be easily measured.

c. **Anticipated Accomplishments:** The major effort during FY89 will be to integrate a 600 GHz SIS mixer into the cryostat and to optimize the system for use as a spectral line receiving system on the CalTech Submillimeter Telescope.

d. **Publications:** Gulkis, S., Frerking, M.A., Swanson, P.N., Wannier, P., and Wilson, W.J.: Submillimeter Heterodyne Receiver for the CalTech Submillimeter Telescope on Mauna Kea: proposal submitted to the NASA Aeronautics and Space Administration Office of Space and Application.

N89-16651

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Observations of Periodic Comets

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

M. S. Hanner

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Selected comets are observed in the infrared with the NASA IRTF and other telescopes as appropriate. The scientific objectives are to characterize the thermal emission from the dust coma, derive dust production rates, detect silicate features near 10 and 20 microns, derive average albedo of the grains, and detect changes in grain size or composition with heliocentric distance as well as differences among comets. Knowledge of the dust environment is essential to S/C design and mission planning for NASA's CRAF mission.

b. FY88 Progress: A report was prepared from Aug. 1987 workshop on Infrared Observations of Comets Halley and Wilson and Properties of the Grains, (NASA SP, in press, M. Hanner, ed.). Comets Wilson, Klemola, Brooks 2, Borrelly, and Bradfield were observed at the IRTF in Sept. 87 and Feb. 88. We detected 10 and 18 micron thermal emission for Wilson at R = 3.74 AU. Both 10 micron CVF spectra and 3 micron CGAS spectra were obtained for Borrelly and Bradfield. A paper on Comet Wilson is in preparation.

c. FY89 Plans: Comet P/Tempel 2 will be extensively observed near perihelion at the IRTF. Although this comet is no longer the target for NASA's CRAF mission, we will surely learn a great deal about short period comets from the observing programs at many wavelendths already planned. A review paper on infrared observational techniques for comets will be prepared for the Bamberg Conference. Papers on P/Borrelly and other comets observed in 1987-88 will be prepared.

d. 1). Hanner, M. S., R. L. Newburn, H. Spinrad and G. J. Veeder (1987). Comet Sugano-Saigusa-Fujikawa (1983V): A Small, Puzzling Comet. Astron. J., 94, 1081.
2). Hanner, M. S., P. N. Kupferman, G. Bailey and J. C. Zarnecki (1987). IR Imaging with JPL's Linear Array Camera, in Infrared Astronomy with Arrays (ed. C. G. Wynn-Williams and E. E. Becklin), p. 205.
3). Veeder, G. J., M. S. Hanner, and D. J. Tholen (1987). The Nucleus of Comet P/Arend-Rigaux. Astron. J., 94, 169.
4). Hanner, M. S., A. T. Tokunaga, W. F. Golisch, D. M. Griep and C. D. Kaminski (1987). Infrared Emission from Halley's Dust Coma during March 1986. A & A, 187, 653.
5). Hanner, M. S., ed (1987). Infrared Observations of Comets Halley and Wilson and Properties of the Grains. NASA Conference Publication, in press.
6). Hanner, M. S. and Newburn, R. L. (1987). Infrared Observations of Comet Wilson. Bull. Amer. Astron. Soc. 19, 893.

1987 RELEVANT PUBLICATIONS

Hanner, M. S., ed (1987). Infrared Observations of Comets Halley and Wilson and Properties of the Grains. (Workshop, Cornell Univ. Ithaca, NY, August 1987). NASA Conference Publication, in press.

Hanner, M. S., P. N. Kupferman, G. Bailey and J. C. Zarnecki (1987). IR Imaging with JPL's Linear Array Camera, in Infrared Astronomy with Arrays (ed. C. G. Wynn-Williams and E. E. Becklin), p. 205.

Hanner, M. S., R. L. Newburn, H. Spinrad and G. J. Veeder (1987). Comet Sugano-Saigusa-Fujikawa (1983V): A Small, Puzzling Comet. Astron. J., **94**, 1081.

Hanner, M. S., A. T. Tokunaga, W. F. Golisch, D. M. Griep and C. D. Kaminski (1987). Infrared Emission from Halley's Dust Coma during March 1986. Astron. Astrophys., **187**, 653.

McDonnell, J. A. M. et al., (incl. Hanner) (1987). The Dust Distribution within the Inner Coma of Comet P/Halley 1982i: Encounter by Giotto's Impact Detectors. Astron. Astrophys., **187**, 719.

Veeder, G. J., M. S. Hanner, and D. J. Tholen (1987). The Nucleus of comet P/Arend-Rigaux. Astron. J., **94**, 169.

N89-16652

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Table Mountain Observatory Support to other programs

PERFORMING ORGANIZATION
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Alan W. Harris

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: The Table Mountain Observatory (TMO) facilities include well equipped 24" and 16" telescopes with a 40" (1m) telescope (owned by Pomona College) due for completion during FY 89. This proposal is to provide operational support (equipment maintenance, setup, and observing assistance) at TMO to other programs.

b. Accomplishments: The program currently most heavily supported by this grant is the asteroid photometry program directed by A. Harris. During 1987, about 20 asteroids were observed, including a near-earth asteroid, 1951 Midas. The photometric observations are used to derive rotation periods, estimate shapes and pole orientations, and to define the phase relations of asteroids. The E class asteroid 64 Angelina was observed, and showed the same "opposition spike" observed of 44 Nysa, last year. Comet observations are made with the narrow band camera system of David Rees, University College London. Observational support and training was provided to students and faculty from the Claremont Colleges for variable star observing programs.

c. Anticipated Accomplishments: We propose to continue the asteroid program, with emphasis on measuring phase relations of low and high albedo asteroids at very low phase angles, and supporting collaborative studies of asteroid shapes. Efforts will be made to observe occultations by asteroids, and to obtain lightcurves so that the rotation phase at the time of occultation will be known. Asteroids which are planned for radar observations will be given special attention, as the combination of radar and photometric data is much more valuable than either observation separately. The JPL IR array camera will be maintained as a TMO facility instrument. The Rees narrow band camera is at TMO and will be used as comet targets become available. Other observing programs will be supported as scheduled on the telescopes, as resources permit.

d. Publications

Harris, A.W., J.W. Young, J. Goguen, H.B. Hammel, G. Hahn, E.F. Tedesco, and D.J. Tholen (1987). Photoelectric lightcurves of the asteroid 1862 Apollo. Icarus 70, 246-256.

Harris, A.W., and 10 co-authors (1988). Photoelectric observations of asteroids 3, 24, 60, 261, and 863. Icarus, in press.

Harris, A.W. and J.W. Young (1988) Asteroid lightcurve observations from 1979-1981. Icarus, submitted.

Harris, A.W. and J.W. Young (1988) Two dark asteroids with very small opposition effects. Lunar and Planetary Science XIX, 447-448.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY ASTRONOMY P.I. RESEARCH SUMMARY

PERFORMING ORGANIZATION

Planetary-Crossing Asteroid Survey (PCAS)

INVESTIGATOR'S NAME

Eleanor F. Helin
Planetology and Oceanographic Section
Jet Propulsion Laboratory
Pasadena, California 91109

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. STRATEGY:

A systematic survey for near-Earth and planet-crossing asteroids is being conducted with the 0.46*m* Schmidt at Palomar to increase the number of known asteroids and establish improved estimates of their populations and size distribution. Access to a limited number of PSS11 plates from the 1.2*m* Schmidt are used also to search for unusual objects. Field pairs from the 0.46*m* are photographed and inspected with a stereomicroscope; new objects are detected and followed to establish definitive orbits. When near-Earth asteroids are discovered, other astronomers are informed so that physical observations can be obtained. With remote sensing results, possible generic relationships are suggested. Population refinements can be accomplished by increasing the number of known asteroids under well-established conditions of search.

B. ACCOMPLISHMENTS:

From 13 observing runs made at Palomar, 215 new asteroids were discovered and reported with good orbits determined for 90. Significant discoveries are Apollo 1988 EG, Amor 1987 QB, and an unusual high inclination asteroid, 1988 EO. Other discoveries of importance include 12 Mars-crossers, 6 Hungarias, and 13 Phocaeas. The discovery of short-period comet Helin, 1988w, which makes a close approach to Saturn, is also notable. The International Near-Earth Asteroid Survey (INAS) continues to produce numerous discoveries which are published in the MPC's. Our Bulgarian colleagues discovered Apollo 1987 SB with confirming Palomar follow-up. Prime mission candidate (3757) 1982 XB, unique Mars-crosser, (3800)1984 AB and (3752)1985 PA, our high inclination INAS discovery, have been recovered and numbered. 1986 LA and 1986 PA are the latest recoveries of faint NEA's and await numbering.

C. ANTICIPATED ACCOMPLISHMENTS:

Monthly observing runs with the 0.46*m* Schmidt will continue. When possible, PSS11 plates will be reviewed for objects of interest. Newly discovered objects will be routinely followed for as long as possible to ensure later recovery. INAS will complement these efforts, both in follow-up, independent and expanded sky coverage. Plans are set for a intensive search for the recovery of 1982 DB using the 1.2*m* Palomar and U.K. Schmidt telescopes.

D. PUBLICATIONS: Attached.

PUBLICATIONS

Planet-Crossing Asteroid Survey (PCAS)

Helin, E. F. (1987), Near-Earth Asteroid Searches: Status and Prospects, from the Evolution of the Small Bodies of the Solar System, 1897, *XCVIII, Corso, Soc. Italiana di Fisica*, Bologna, Italy.

Sekanina, Z., S. M. Larson, G. Emerson, E. F. Helin and R. E. Schmidt (1987) The Sunward Spike of Halley's Comet, *Astron. and Astrophys.*, **187**, 645-649.

Helin, E. F., S. C. Singer-Brewster, J. T. Alu (1987), Near-Earth Asteroid Discoveries from the Palomar Sky Survey II, 1987 AAS/DPS Meeting, Pasadena, CA, *Bull. Amer. Astron. Soc.*, **19**, No. 3, 840 (abstract).

Bambery, R. J., B. A. Goldberg, E. F. Helin (1987), Development and Application of New Digital Image Processing Techniques to Groundbased Observations, AAS/DPS Meeting, Pasadena, CA, *Bull. Amer. Astron. Soc.*, **19**, No. 3, 851 (abstract).

Helin, E. F., S. Singer-Brewster, J. T. Alu (1987), Planet-Crossing Asteroid Search, JPL Highlights, 1987.

Helin, E. F. (April, 1988), Gli Asteroidi Vicini, *Astronomia*, **No. 76**, 30-38.

Helin, E. F. (1988), Discover, Recovery and Physical Observations of (3757) 1982 XB: A Prime Mission Candidate, Asteroids II Conference, Tucson, AZ (abstract).

Discovery and Astrometric Position Publications

International Astronomical Union Circulars:

1987: P/Comet Helin, 1987w, IAU Circ Nos 4448, 4449; 1987 QB, IAU Circ Nos 4451, 4455; 1987 SB, IAU Circ No 4464; 1987 OA, IAU Circ No 4436; 1987 PA, IAU Circ No 4437; 1987 OA, IAU Circ No 4441

1988: 1988b, IAU Circ No 4548; 1988 EG, IAU Circ No 4565, 4571 and 4573

Minor Planet Circulars:

1987: MPC Nos 11489-490, 11597-601, 11707-710, 11809-811, 11923-924, 12039-040, 12180-181, 12285-286, 12411-412, 12519-520

1988: MPC Nos 12652, 12766, 12910, 13019-020, 13035, 13105-107, 13109, 13130-13133

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

"Interiors of the Giant Planets"

PERFORMING ORGANIZATION

Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721

INVESTIGATOR'S NAME

W.B. Hubbard

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) This theoretical/observational project constrains interior structure of Jovian planets through observational data. We continue to concentrate on Neptune in support of the 1989 Voyager encounter. Occultations of stars by Neptune are observed from the Tucson area and from Chile to obtain information about Neptune's atmosphere and to continue to search for Neptune arcs. Occultations by other solar system objects are also observed as part of collaborative efforts from time to time. (b) We derived new results on the structure of scintillations in the central flash occultation by Neptune on 20 August 1985 (results related to the mean light curve were published last year). Our analysis shows that scintillations are present throughout the lightcurve, both near the half-intensity points (at a pressure of 1 microbar) and near the central flash (at 0.4 mbar). Near the planetary limb, the scintillations are extended parallel to the limb, but near the shadow center, they are extended in a radial direction. We collaborated with Ramesh Narayan to derive a theory relating the scintillations to density fluctuations in Neptune's atmosphere. The theory will ultimately enable us to test whether the scintillations are caused by internal gravity waves in Neptune's upper atmosphere. We successfully observed the 9 July 1987 Neptune occultation from two stations in the Tucson area, in collaboration with G. and R. Rieke, R. Marcialis, and H. Campins. Further data on Neptune's atmosphere were obtained, but no ring arcs were detected. On 8 December 1987 we successfully observed an occultation by the asteroid Bamberga, in collaboration with a Lowell Observatory group. The resulting data will provide a more accurate determination of the asteroid's size. In collaboration with D. Tholen, we showed that geometrical optics are adequate for interpreting Pluto/Charon mutual events. (c) We will continue to carry out multistation observations of favorable Neptune occultations. The next opportunity will be on 9 July 1988, and will be observed from the MMT in the Tucson area. We are also analyzing 2-micron CCD images of 1989 Neptune positions in an effort to find future occultations of 2-micron stars which have not been discovered by shorter-wavelength photometry. Such an effort for the 1988 path found no additional opportunities.

(d) Publications

Millis, R. L., L. H. Wasserman, O. G. Franz, R. A. Nye, R. C. Oliver, T. J. Kreidl, S. E. Jones, W. Hubbard, L. Lebofsky, R. Goff, R. Marcialis, M. Sykes, J. Frecker, D. Hunten, B. Zellner, H. Reitsema, G. Rafert, E. Strother, J. Smith, H. Povenmire, B. Jones, D. Kornbluh, L. Reed, K. Izor, M. F. A'Hearn, R. Schnurr, W. Osborn, D. Parker, W. T. Douglas, J. D. Beish, A. R. Klemola, M. Rios, A. Sanchez, J. Piironen, M. Mooney, R. S. Ireland, and D. Leibow: The Size, Shape, Density and Albedo of Ceres from Its Occultation of BD +8°471. Icarus **72**, 507, 1987.

Hubbard, W. B., and M. S. Marley: Structure of the Jovian Envelope and the Equation of State of Dense Hydrogen, in Strongly Coupled Plasma Physics (H. E. DeWitt and F. J. Rogers, eds.), Plenum Publishing Co., 1987, pp. 407-413.

Hubbard, W. B., Phillip D. Nicholson, Emmanuel Lellouch, Bruno Sicardy, Andre Brahic, Faith Vilas, Patrice Bouchet, Robert A. McLaren, Robert L. Millis, Lawrence H. Wasserman, J. H. Elias, K. Matthews, J. D. McGill, and C. Perrier: Oblateness, Radius, and Mean Stratospheric Temperature of Neptune from the 1985 August 20 Occultation. Icarus **72**, 635, 1987.

Hubbard, W. B., E. Lellouch, B. Sicardy, A. Brahic, F. Vilas, P. Bouchet, R. A. McLaren, and C. Perrier: Structure of Scintillations in Neptune's Occultation Shadow. Astrophys. J. **325**, 490, 1988.

Hubbard, W. B., and Ramesh Narayan: Theory of Anisotropic Refractive Scintillation -- Application to Stellar Occultations by Neptune. Astrophys. J. **325**, 503, 1988.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Studies of Extended Planetary Atmospheres (NAGW-596)

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
The University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Donald M. Hunten

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Spectroscopic observations of gases and plasmas in the Jupiter system, and related phenomena such as the recently-discovered sodium atmospheres of Mercury and the Moon. Observations of other planets as opportunities arise.

b. Cunningham's work on Jupiter spectroscopy is complete. The optical thickness of the ammonia cloud increases from about 3 in the morning to 6 at sunset. This effect seems to be due to the combination of internal heat flow and a convective region heated at the top, giving strong convection at night and none during the day. Near-simultaneous methane data are of poor quality, but are consistent with this picture.

Schneider's work on the sodium environment of Io is also complete. The eclipse data extend to nearly 10 Io radii and nicely match the densities in the outer regions (to ~100 Io radii) obtained from the intensity scattered in the D lines. Another data set shows very fast jets of sodium (up to 100 km/sec), frequently tilted out of the orbital plane. We seem to be seeing neutralized ions, not from the torus itself but from atmospheric sodium ionized and then quickly neutralized.

The data set on Mercurian sodium has been augmented, and supplemented by IR reflectance spectra obtained at the IRTF. They show Christiansen peaks that are diagnostic of surface composition.

Lunar sodium has been observed; the scale height is around 60 km, as expected, but the density is very small, 1% of the Mercury value.

Data have been taken of the night side of Venus, searching for auroral emission at 6300 A and for lightning flashes at 7774 A. The extensive data processing needed to remove scattered light from the day side is about to begin.

Water vapor on Mars has been mapped in a collaborative program with a group at GSFC observing ozone by heterodyne spectroscopy.

c. Analysis (A. Tyler) of the accumulated data on Mercurian sodium, seeking evidence of spatial and temporal variations with due account for seeing quality.

Further work on sodium far from Io is planned, in collaboration with R.A. Brown and N. Schneider.

Further observations of lunar sodium, mainly in connection with other observations.

Analysis of the existing data on Venus aurora and lightning, and Mars water vapor (B. Rizk). Possible survey of Venus water vapor.

Occultations will be observed as opportunities arise.

RELEVANT REFERENCES

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Cunningham, C. C., D. M. Hunten, and M. G. Tomasko (1988) Methane spectroscopy of Jupiter. Icarus, submitted.

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C-2

N89-16656

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radiative Transfer in Planetary Atmospheres

PERFORMING ORGANIZATION

Department of Physics and Astronomy
University of Massachusetts
Amherst, MA 01003

INVESTIGATOR'S NAME

William M. Irvine

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Theoretical techniques and observations at millimeter wavelengths are combined to study the atmosphere of planets and comets, planetary and satellite regoliths, and planetary rings.

b. Analysis continued of the very high quality data on the 18cm OH line observed in recent comets. The high spectral resolution and high signal-to-noise make these lines ideal for study of the kinematics in cometary comae. A model of the collisional quenching of the inversion of the lambda doublet responsible for the OH radio emission has been developed by P. Schloerb. For conditions appropriate to Halley's Comet, collisional quenching should lead radio observers to systematically underestimate the OH parent production rate by a factor of approximately 3 relative to its actual value, which is very consistent with differences observed between radio and ultraviolet-derived production rates. Modeling is likewise continuing for the line profiles observed in the lowest rotational transition of HCN in Comet Halley in order to better estimate the excitation and hence the abundance of HCN, as well as the kinematics of parent molecules in the coma. A collaborative program to combine data from the FCRAO 14m antenna with interferometric data obtained at the Hat Creek Radio Observatory is allowing aperture synthesis mapping of Venus in the CO J=1-0 line. Graduate student Swade completed his analysis of observations of molecular emission from the nearby interstellar cloud L134N. Chemical gradients have been demonstrated which may be related to variations in the depletion of oxygen onto interstellar grains in the form of water-ice.

c. Modeling of the OH line profiles and production rate for Comets Halley, Giacobini-Zinner, Thiele, Hartley-Good, and Wilson will continue. Study of the thermodynamics and excitation of HCN in the coma of Comet Halley will also continue. The question of whether cometary HCN is a parent molecule or originates in a distributed source in the coma is being investigated. Multiple frequency carbon monoxide observations for Venus and Mars will take place, and analysis will be carried out for the aperture synthesis observations of Venus. The study of radiative transfer in planetary and satellite regoliths or cometary nuclei will be extended with particular reference to analyzing data obtained on the Phobos Mission concerning the structure and composition of the regolith of Phobos.

d. During the past year 8 articles have been published in scientific journals or conference proceedings (see attached list) and another two have appeared as abstracts.

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Tacconi-Garman, L. and Schloerb, F.P.: Models of the OH 18cm Line Profiles of Comet Halley, in Cometary Radio Astronomy, ed. Irvine, W.M., Schloerb, F.P., and Tacconi-Garman, L. (NRAO Workshop #17, Green Bank, WV), 143-148, 1987.

N89-16657

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Ground Based Infrared Astronomy

PERFORMING ORGANIZATION

Planetary Systems Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME | TEL. NO.

D. E. Jennings | 301-286-7701

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Infrared spectroscopic instrumentation has been developed for ground-based measurements of astrophysical objects in the intermediate infrared. A conventional Michelson interferometer is limited for astronomical applications in the intermediate infrared by quantum noise fluctuations in the radiation from the source and/or background incident on the detector, and the multiplex advantage is no longer available. One feasible approach to recovering the multiplex advantage is post-dispersion. The infrared signal, after passing through telescope and interferometer, is dispersed by a low resolution grating spectrometer onto an array of detectors. The feasibility of the post-dispersion system has been demonstrated with observations of astrophysical objects in the 5 and 10 μm atmospheric "windows" from ground-based telescopes. Ground-based observations will be made during FY87/88 with the post-dispersion system at Kitt Peak using the FTS at the 4-meter telescope, and McMath telescope.

b) During FY87/88 the post-disperser was used at the Kitt Peak 4-meter telescope and McMath telescope with facility Fourier transform spectrometers. Jupiter, Saturn, Mars, and Venus were observed. On Jupiter, the resolution at 12 microns was 0.01 cm^{-1}, considerably higher than had been achieved previously. The specrum contains Jovian ethane and acetylene emission. Construction was begun on the large cryogenic grating spectrometer.

c) Proposals will be submitted for FY89 to observe Jupiter, Saturn, Mars and Venus with the 4-meter and McMath FTS using the Goddard pot-disperser. Manuscripts have been submitted and are being prepared describing the instrument and our observations.

d) Publications

"A Cryogenic Grating Postdisperser for Astronomical Observations using Fourier Transform Spectrometers", G. Wiedemann, D. Jennings, V. Kunde, G. Lamb, H. Moseley, and R. Hanel, submitted.

"Detection of 12 Microns MgI and OH Lines in Stellar Spectra", D. Jennings, D. Deming, G. Wiedemann, J. J. Keady, Ap. J., 310, L39.

"Detection of -13 Ethane in the Atmosphere of Jupiter", G. Bjoraker, D. Jennings, and G. Wiedemann, in preparation.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Optical Investigation of Comet Halley

PERFORMING ORGANIZATION

Department of Earth, Atmospheric and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

INVESTIGATOR'S NAME

David Jewitt

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a). **Strategy**: The physical properties of Comet P/Halley are being monitored from the ground using state of the art optical detectors. The long time base (1982 - present) of the observations provides a unique record of the development of activity in a single comet. In addition, physical properties of other comets are measured to provide a reference against which comet Halley may be compared.

(b). **Accomplishments**: Results for the past year include

(i). Publication of our first results on the surface brightness profiles of dust comets. The profiles yield information about the physical properties of the dust and about the influence of solar radiation pressure on the spatial dust distribution. A 3 - dimension Monte Carlo model was developed to interpret the measured profiles.

(ii). CCD measurements of Comet Bowell show that the activity of comets can persist at least to heliocentric distances R = 13.6 AU. This is clearly beyond the range of distances in which activity can be driven by water sublimation.

(iii). A study of the back-scattering phase angle dependences of 5 comets (including Halley) shows evidence for small linear phase coefficients in each case. The phase curves of the comets differ from the phase curve of the Zodiacal Cloud.

(iv). Temporal monitoring of P/Halley continues. The main finding is that an extensive coma persists in P/Halley at R > 6 AU.

(c). **Future Work**:

(i). The Monte Carlo coma model will be modified to include a time dependent source function. This modification will make the model useful for the interpretation of comae which are not in steady state.

(ii). Photometric monitoring of P/Halley will continue. The science objectives are to determine the full lightcurve and to determine the nucleus rotation state.

NASA Publications of David Jewitt (1987)

D. C. Jewitt and K. J. Meech (1987), "Surface Brightness Profiles of Ten Comets", Astrophysical Journal, **317**, 992.

K. J. Meech and D. C. Jewitt (1987), "Comet Bowell at Record Heliocentric Distance", Nature, **328**, 506.

K. J. Meech and D. C. Jewitt (1987), "Observations of Comet P/Halley at Minimum Phase Angle", Astron. & Astrophys., **187**, 585 - 593.

D. C. Jewitt and K. J. Meech (1988), "Optical Properties of Cometary Nuclei and a Preliminary Comparison with Asteroids", Ap. J., **328**, 974 - 986.

N89-16659

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

INFRARED OBSERVATIONS OF OUTER PLANET SATELLITES

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME	TEL. NO.
JOHNSON, T. V.	(818) 354-2761

DESCRIPTION *(a. Brief statement on strategy of investigation. b. Progress and accomplishments of prior year. c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVE: This tasks supports IR observations of the outer planet satellites. These data provide vital information about the thermophysical properties of satellite surfaces, including internal heat sources for Io. Observations include both broad and narrow band measurements in the 2 to 20μm spectral range. Most observations are carried out at the IRTF facility on Mauna Kea. Types of observation and target priority are determined to make maximum use of existing data from Voyager and other missions, support on-going and planned missions such as Galileo, and to develop techniques and data for planning new missions and instrumentation.

B. PROGRESS: The program in the last year has aimed at obtaining longitude coverage on Io to establish stability of hot spot patterns previously reported. Several runs produced the most complete data set for an apparition since we started the program in 1983; unfortunately bad weather limited coverage of key longitude ranges containing the largest known hot spot Loki. Among the preliminary results is the observation of an outburst in Io's thermal flux that was measured at 4.8, 8.7 and 20μm. Analysis of those data has given the best evidence to date of silicate volcanism on Io; this is one of the most significant pieces of the puzzle as to the relative roles of silicate and sulfur volcanism on Io. We are collaborating with J. Goguen (NRC RRA) to finish reduction of mutual event data, which have already improved ephermeris information for the satellites. The data appear to place significant limits on the characteristics of any leading side hot spots. Our earlier data were used in two published analysis papers concerning correlations of hot and dark regions and models for the occulation data at several wavelengths.

C. PROPOSED WORK: During 1988, we plan a series of 3 to 4 observing sessions. Emphasis will be on further study of high temperature eruptive events on Io, on studying the suspected variability of the high temperature component(s) suggested by last year's data and on obtaining longitude coverage constraining the hot spots in the Loki region.

D. SUMMARY BIBLIOGRAPHY: Johnson, T. V. et al, Io: Evidence for silicate volcanism in 1986; Goguen, J. D. et al, Io hot spots: IR photometry of satellite occultations; Goguen, J. D. et al., Io hot spots: Satellite occultations of sources.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Goldstone Solar System Radar

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Raymond F. Jurgens

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. **Strategy**: (1) Planning, direction, experimental design, and coordination of data-acquisition and engineering activities in support of all Goldstone planetary radar astronomy. This work demands familiarity with the various components of a planetary radar telescope (transmitter, receiver, antenna, computer hardware and software) as well as knowledge of how the entire system must function as a cohesive unit to meet the particular scientific objectives at hand in a given observation. (2) Support radar data-processing facilities, currently being used for virtually all Goldstone data reduction: a VAX 11/780 computer system, an FPS 5210 array processor, terminals, tape drives, and image-display devices, as well as a large body of data-reduction software to accommodate the variety of data-acquisition formats and strategems.

b. **Accomplishments**: (1) Successful 113-cm radar observation of Callisto (led by R. M. Goldstein) and the near-Earth asteroid 1981 Midas (led by S. Ostro), and Goldstone/VLA radar observations of Saturn's rings (led by D. O. Muhleman). [Note: Enlargement of Goldstone's 64-m antenna to 70 m during 10/87-6/88 precluded observations during that period.] (2) Completion of quick-look verification programs for data taken with phase-coded cw (i.e., ranging) waveforms, applicable to Venus, the Moon, and small bodies. (3) Management of the radar data-processing facilities described above. (4) Definition of scientific and engineering requirements on instrument performance, radar system configuration, and personnel, for all 1988 Goldstone radar investigations.

c. **Anticipated Accomplishments**: (1) Oversee execution during 1988-89 of observations of various targets, including Venus, Mars, the Martian satellites, the Galilean satellites, and at least two near-Earth asteroids. (2) Completion of verification and analysis software for new data-taking systems to be implemented as soon as the main antenna resumes operation. One of these systems acquires wide-band (up to ~10 MHz), echo power spectra, and as such will be valuable for a variety of cw studies. (3) Write core material for the new Support Instrument Requirements Document (SIRD), which constitutes the technical definition of Goldstone capabilities for NASA. (4) Manage the Radar VAX.

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d. Publications:

Clark, P. E., M. A. Leake, and R. F. Jurgens (1988). Goldstone Radar Observations of Mercury. In Mercury (C. R. Chapman and F. Vilas, eds.), Univ. of Arizona Press, in press.

Jurgens, R. F., M. A. Slade, L. Robinett, S. Brokl, G. S. Downs, C. Franck, G. A. Morris, K. H. Farazian, and F. P. Chan (1988). High-Resolution Images of Venus from Ground-Based Radar. Geophys. Res. Lett., in press.

Jurgens, R. F., M. A. Slade, and R. S. Saunders (1988). Evidence for Highly Reflecting Materials on the Surface of Venus. Science **240**, 1021-1023

Ostro, S. J. (1988). Radar Observations of Asteroids. Chapter in Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press, in press.

Ostro, S. J., D. K. Yeomans, P. W. Chodas, R. F. Jurgens, R. M. Goldstein, and T. W. Thompson (1988). Radar Observations of Asteroid 1986 JK. Submitted to Icarus.

Roth, L. E., R. S. Saunders, G. S. Downs, and G. Schubert (1988). Radar Altimetry of Large Martian Craters. Submitted to Icarus.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radar Observations of the Inner Solar System

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA. 91109

INVESTIGATOR'S NAME

Raymond F. Jurgens

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. **Strategy**: Goldstone radar observations of Mars, Venus, Mercury, and the Moon, including high-resolution delay/Doppler mapping, altimetry, and dual-polarization observations designed to provide information about those bodies' surfaces that is new and is unlikely to be provided by upcoming space missions. Concurrent objectives involve dynamical information: maintenance of Mars ephemeris accuracy, Mercury "closure-point" ranging for relativity theory testing, and refinement of spin-vector estimates for Venus and Mercury. This task has been renamed to reflect accurately the research it supports.

b. **Accomplishments**: The backlog of unprocessed Venus data has been sharply reduced; most images from the 1980-82 conjunctions, and half of those from 1986, are essentially finished. Articles reporting selected results (e.g., identification of very highly relecting materials in the lowland plains) are reported by Jurgens et al.(1988, *Science* **240**, 1021-1023; and *Geophys. Res. Lett.*, in press). Suitably formatted data have been distributed to (non-JPL) scientific collaborators for geologic analysis, and to the Magellan project.

c. **Anticipated Accomplishments**: (1) Mars range/Doppler observations planned for the closest opposition until 2003 will provide altimetric profiles and Hagfors slope and reflectivity parameters at latitudes from -19° to -24°, and dual-polarization, 13.5-cm spectral measurements will elucidate the global variations in the surface's small-scale structural complexity (i.e., "roughness"). (2) For Venus, up to 11 images of previously unmapped equatorial regions (inaccessible to Arecibo) will be acquired at near-normal incidence angles (i.e., with a viewing geometry very different from the typically ~30° for Magellan). The best resolution in these images will be ~1 km. (3) For Mercury, in addition to ranging for orbital parameter refinement in an ongoing program, we propose radar mapping of portions of the unimaged hemisphere of Mercury at resolutions ~10 km. (4) Acquisition of high-resolution (~100-m) reflectivity imaging and altimetry data for the Moon at the Magellan wavelength (13 cm).

d. Publications:

Clark, P. E., M. A. Leake, and R. F. Jurgens (1988). Goldstone Radar Observations of Mercury. In Mercury (C. R. Chapman and F. Vilas, eds.), Univ. of Arizona Press, in press.

Jurgens, R. F., M. A. Slade, L. Robinett, S. Brokl, G. S. Downs, C. Franck, G. A. Morris, K. H. Farazian, and F. P. Chan (1988). High-Resolution Images of Venus from Ground-Based Radar. Geophys. Res. Lett., in press.

Jurgens, R. F., M. A. Slade, and R. S. Saunders (1988). Evidence for Highly Reflecting Materials on the Surface of Venus. Science **240**, 1021-1023.

Roth, L. E., R. S. Saunders, G. S. Downs, and G. Schubert (1988). Radar Altimetry of Large Martian Craters. Submitted to Icarus.

N89-16662

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY SUBMILLIMETER SPECTROSCOPY

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME	TEL. NO.
Klein, M.J.	(818) 354-7132

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year, c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Develop a comprehensive observational and analytical program to study solar system physics and meteorology by measuring molecular lines in the millimeter and submillimeter spectra of planets and comets. A primary objective is to conduct observations with new JPL and Caltech submillimeter receivers at the Caltech Submillimeter Observatory (CSO) on Mauna Kea, Hawaii. A secondary objective is to continue to monitor the time variable planetary phenomena (e.g Jupiter and Uranus) at centimeter wavelengths using the NASA antennas of the Deep Space Network (DSN).

(b) Progress (FY 88): Halley: Paper submitted on H2O Observations from KAO Uranus: Published paper on a geometrical beaming model to account for Uranian kilometric radio emission observed by Voyager.Jupiter: Continued Jupiter Patrol observations at 13-cm; Reported tentative correlation between variations of Jovian synchrotron emission and solar wind ion density. Venus: NRAO & DSN obserations used to set upper limit to H2SO4 in Venus atmosphere (1st draft of paper written).

(c) Prepare observing program for CSO Planetary observations. Continue study of the effect of H2SO4 abundance on Venus microwave spectrum. Conduct new observations of the time variations of the microwave spectra of the atmosphere of Uranus and the magnetosphere of Jupiter using the newly upgraded DSN 70-m antennas. Participate in International Jupiter Watch measurement campaigns. Begin high time resolution measurements of Jupiter with the Hot Creek 26 m antenna.

(d) de Pater & Klein, 1988, Review Paper in Proc. of Workshop on Time Variable Phenomena in Jovian System (Flagstaff AZ) (in press).
Klein, Thompson & Bolton, 1988 in Proceedings of Workshop on Time Variable Phenomena in the Jovian System (Flagstaff AZ) (in press).
Gulkis , 1987 "Radio Astronomy, Planetary". In Encyclop. of Physical Sci. and Tech., 11, Academic Press;
Gulkis and Carr 1987, J. Geophys. Res., 92 (A13).
Gulkis, et al., 1987 (Halley Paper) submitted to Astron. and Astrophys.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Spectroscopy of Jupiter and Saturn

PERFORMING ORGANIZATION

Astronomy Program
State University of New York at Stony Brook

INVESTIGATOR'S NAME

Roger Knacke, Principal Investigator

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: High resolution infrared spectroscopy provides unique insights into the chemistry and dynamics of the atmospheres of Jupiter and Saturn. The 5 μm spectral region, which is transparent to deep levels, is particularly useful for the identification of molecules that are present at very low (parts per billion) concentrations. These are tracers of convective and strongly non-equilibrium processes in the atmospheres. High resolution ground-based spectroscopy complements Voyager and Galileo measurements. Spectroscopy is sensitive to lower mixing levels for selected molecules, while the on-board mass spectrometers probe molecules that are spectroscopically inaccessible.

b. Accomplishments: We completed analysis and modeling of the 4.7 μm carbon monoxide band in Jupiter. CO is present at a mole fraction of $1.6\pm0.3\times10^{-9}$ and concentrated in the troposphere. At this abundance, it must be convected upward from much deeper levels in Jupiter where the temperature is near 1100K. Thus CO is a tracer of the deep atmosphere which is otherwise unobservable. The oxygen abundance in Jupiter (as measured by the CO abundance) is near solar. Chemical or physical process must deplete the major oxygen carrier, H_2O. Germane, GeH_4, was discovered on Saturn at a mole fraction of $4\pm2\times10^{-10}$. The spectra show evidence for a strong reflecting layer. The data also contain an absorption band near 2115 cm^{-1}, which we propose is of arsine, AsH_3.

c. Anticipated Accomplishments: The results show that molecules at extremely low abundances are observable with high resolution spectroscopy in the 5 μm band. A significant new development is the completion (by French laboratories) of high resolution spectroscopy and molecular data of phosphine, PH_3, which has hundreds of lines in the Jovian spectrum. With the new laboratory data we can distinguish weak lines from the phosphine forest for the first time. We plan to observe both Jupiter and Saturn in the AsH_3 region. Confirmation of this gas would corroborate the strongly convective properties of the deep atmosphere. Several other unidentified features in the spectra will be analyzed in the light of the new phosphine data. These may be features of species whose identification would provide new information about giant planet composition and chemistry.

d. Publications

Noll, K. S., Knacke, R. F., Geballe, T. R., and Tokunaga, A. T. 1988, The Origin and Vertical Distribution of Carbon Monoxide in Jupiter, Ap. J., 324, 1210-1218.

Noll, K. S., Knacke, R. F., Geballe, T. R., Tokunaga, A. T. 1988, Evidence for Germane in Saturn, Icarus, in press.

N89-16664

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Advanced Infrared Astronomy

PERFORMING ORGANIZATION

Planetary Systems Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt MD 20771

INVESTIGATOR'S NAME

T. Kostiuk/D. Deming/M. Mumma

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

a. Strategy: This task supports the application of infrared heterodyne and Fourier transform spectroscopy to ultra-high resolution studies of molecular constituents of planetary astomspheres and cometary comae. High spectral and spatial resolutions are especially useful for detection and study of localized, non-thermal phenomena in low temperature and low density regions, for detection of trace constituents and for measurement of winds and dynamical phenomena such as thermal tides. Measurement and analysis of individual spectial lines permits retrieval of atmospheric molecular abundances and temperatures and thus, information on local photochemical processes. Determination of absolute line positions to better than 10^{-8} permits direct measurement of gas velocity to a few meters/sec. Observations are made from ground based heterodyne spectrometers at the Kitt Peak McMath solar telescope and from the NASA Infrared Telescope Facility on Mauna-Kea, Hawaii. FTS observations are conducted from ground base facilities and the Kuiper Airborne Observatory.

b. Accomplishments: Wind velocities at 110km altitude on Venus were extracted to ~1 m/sec from measurements of non-thermal emission cores of 10.3 μm CO_2 lines. Results indicate a subsolar to antisolar circulation with a small zonal retrograde component. Results are now being compared to existing 2-D dynamical models. Measurements of ozone distribution on Mars were made in June, 1988 at the IRTF. The study of hydrocarbon abundances and variability on Jupiter is proceeding. Increased temperature, photochemistry and abundances in the polar regions was investigated. The first measurement of ethylene (10.5 μm) on Jupiter was made, retrieving mole fraction ~4×10^{-10}. Continuing analysis of FTS spectra of comets Halley an Wilson produced new information on the temperature of the nucleus and excitation conditions in the inner coma. A model for the detection of formaldehyde in comets was developed and initial observations were made on Comet Bradfield from the Kitt Peak 4 m FTS.

c. Anticipated accomplishments: Analysis of Venus wind data will be completed, dynamical models tested and modified accordingly. Wind velocities near 70 km on Mars will be measured and the study of mesospheric dynamics will continue. Confirming measurements of ethylene on Jupiter will be made and its spatial distribution studied. Behavior of hydrocarbons in the Jovian auroral region will be further investigated and appropriate theoretical models developed. Attempts to observe H_2CO (3.7 μm) on bright comets "of opportunity" and the development of the detailed model of cometary comae (radiative transfer and asymmetric outflow) will continue.

d. Publications:

1987 "Infrared Investigation of Water in Halley's Comet", H. A. Weaver, M. J. Mumma, and H. P. Larson, Astronomy and Astrophysics, 187, 411-418.

1987 "The Ortho-Para Ratio of Water Vapor in Comet Halley", M. J. Mumma, H. A. Weaver, and H. P. Larson, Astronomy and Astrophysics 187, 419-424.

1987 "Kinematic Properties of the Neutral Gas Outflow from Comet Halley", H. P. Larson, M. J. Mumma, and H. A. Weaver, Astronomy and Astrophysics 187, 391-397.

1987 "Variability of Ethane on Jupiter", T. Kostiuk, F. Espenak, M. J. Mumma, D. Deming, and D. Zipoy, Icarus 72, 394-410.

1988 "Airborne Infrared Spectroscopy of Comet Wilson 1986 and Comparisons with Comet Halley", H. P. Larson, H. A. Weaver, M. J. Mumma, and S. Drapatz, Ap. J. (submitted).

1988 "Possible Identification of the 3.4 μm Emission Feature in Comets", A. C. Danks, D. L. Lambert, and M. J. Mumma, Proc. Cornell Cometary Grain Workshop (in press).

1988 "Is Ethane Varying in the Jovian North Polar "Hot Spot"?, T. Kostiuk, F. Espenak, and M. J. Mumma, Proc. Intl. Conf. Time-Variable Phenomena in the Jovian System, (in press).

N89-16665

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Infrared Observations of Solar System Objects

PERFORMING ORGANIZATION
University of Arizona
Lunar and Planetary Laboratory
Tucson, AZ 85721

INVESTIGATOR'S NAME

Larry A. Lebofsky

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. **Strategy**: This program is a continuing effort to study the near infrared (reflected) to thermal infrared flux from asteroids and other airless bodies using groundbased telescopes. The goal of the observations is to investigate the mineralogy and thermophysical properties of these bodies and to support present and potential future missions such as Galileo, CRAF, IRAS and SIRTF.

b. **Accomplishments**: During the past year, we have continued our search for water of hydration on asteroids. 1) Our work has shown that water in the form of hydrated silicates does not exist on the surfaces of the outerbelt asteroids. This implies that the water we see on the c-class asteroids is most likely aqueous alternative products. That water in the ultraprimitive asteroids may be in the form of ice rather than water of hydration. 2) We are also continuing our work on the thermal properties of asteroids. We have found that the lightcurve of 532 Herculina is done primarily to shape rather than the proposed surface albedo variation. 3) In collaboration with other groups we have taken advantage of the mutual events between Pluto and its satellite Charon; we have discovered water ice on the surface of Charon and are studying the surface composition of Pluto.

c. **Anticipated Accomplishments**: During the next year, we will continue to study the distribution of volatiles on asteroids. We will be concentrating on the fainter outer belt asteroids for which we have little data. We will also be working on refining our groundbased and IRAS thermal models with emphasis on improved thermophysical models and investigation of the discrepancies between groundbased and IRAS results. Finally, we will be continuing our studies of the spectral emission of Mercury for the determination of surface composition.

d. PUBLICATIONS

Buie, M. W., Cruikshank, D. P., Lebofsky, L. A., and Tedesco, E. F., Water frost on Charon, Nature 329, 522-523, 1987.

Hubbard, W. B., Rieke, G. H., Rieke, M. J., Lebofsky, L. A., and Marcialis, R. L., A grazing occultation by Neptune on 4 May 1986, Icarus (in press), 1988.

Lebofsky, L. A., Greenberg, R., Tedesco, E. F., and Veeder, G. J., Infrared lightcurves of asteroids 532 Herculina and 45 Eugenia: Proof of the absence of significant albedo markings, Icarus (in press), 1988.

Lebofsky, L. A., Jones, T. D., and Herbert, F., Asteroid volatile inventories, Atmospheres (in press), 1988.

Lebofsky, L. A., and Spencer, J. R., Radiometry and thermal modeling of asteroids, (R. Binzel, Ed.), University of Arizona Press, Tucson, AZ (submitted), 1988.

Sykes, M. V., Cutri, R. M., Lebofsky, L. A., and Binzel, R. P., IRAS serendipitous survey observations of Pluto and Charon, Science 237, 1336-1340, 1987.

Tyler, A. L., Kozlowski, R. W. H., and Lebofsky, L. A., Determination of rock type on Mercury and the Moon through remote sensing in the thermal infrared, (submitted to Geophys. Res. Lett.), 1988.

N89-16666

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Outer Planet Studies — NSG–7499

PERFORMING ORGANIZATION

Lowell Observatory
1400 West Mars Hill Road
Flagstaff, Arizona 86001

INVESTIGATOR'S NAME

Barry L. Lutz

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

The tasks of this grant include observational studies of the composition, structure and variability of planetary and satellite atmospheres, and the investigation of the problems associated with the fundamental calibration of these data. These studies are essential to providing "ground-truth" support for observations of the solar system by NASA's missions, including the *Voyager* and *Galileo* spacecraft, the *Hubble Space Telescope*, and the proposed *CRAF-Cassini* mission. Complementary spectroscopic observations of comets were added in BY88 to support NASA's cometary program goals of the *CRAF-Cassini* mission. A very modest laboratory effort is also maintained to provide essential data needed by these observational programs, which may be otherwise unavailable.

Main accomplishments during BY88 include: (1) Discovery of HDO in the spectrum of Mars and the first determination of the D/H ratio in its atmosphere; (2) Completion and publication of our study of CH_3D in the spectrum of Titan and a determination of the mixing ratio in its atmosphere; (3) Completion of our observations of CH_3D in the spectrum of Neptune and a preliminary analysis of the CH_3D/CH_4 mixing ratio in its atmosphere.

Major efforts proposed for BY89 include: (1) Completion of our analysis of CH_3D in the spectrum of Neptune and a determination of the CH_3D/CH_4 ratio in its atmosphere, as part of our groundbased support of the *Voyager* mission encounter with Neptune in 1989; (2) Search for HDO in the atmosphere of Venus as part of our investigation of the distribution of deuterium in the solar system and its relationship to the origin and evolution of the planets; (3) Completion of time series of spectrophotometric observations of Neptune and a determination of its geometric and Bond albedos as part of our study of temporal variability of its atmosphere, in preparation for the 1989 *Voyager* encounter; (4) Publication of the recalibration of the Sun against Vega and continuation of our study of the fundamental calibration problems associated with solar analogs, needed to accurately determine planetary albedos on a common photometric scale; (5) Continuation of our times series of spatially resolved spectrophotometric observations of the Jovian belts and zones to characterize the spatial and temporal variations of the Jovian atmospheric structure in support of the *Galileo* mission.

PAPERS PUBLISHED IN REFEREED JOURNALS AND MEETING PROCEEDINGS IN BY 1987/1988

"The Solar System/Interstellar Medium Connection: Gas Phase Abundances" (invited review, B. L. Lutz), in *Interstellar Processes* (D. J. Hollenbach and H. A. Thronson, Jr., eds.). D. Reidel Publishing Company, Dordrecht, 1987.

"Monodeuterated Methane in the Outer Solar System. II. Its Detection on Uranus at 1.6 Microns" (C. de Bergh, B. L. Lutz, T. Owen, J. Brault, and J. Chauville), *The Astrophysical Journal*, 15 June 1988.

"Deuterium on Mars: The Abundance of HDO and the Value of D/H" (T. Owen, J.-P. Maillard, C. de Bergh, and B. L. Lutz), *Science*, in press.

"Spatial and Temporal Variations in the Atmosphere of Jupiter: Polarimetric and Photometric Constraints" (B. E. Carlson and B. L. Lutz), in *Proceedings of the International Workshop on Time-Variable Phenomena in the Jovian System*, NASA Special Publication (M. J. Belton and R. A. West, eds.), in press.

N89-16667

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
ASTEROID TEAM

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME
MATSON, D. L.

TEL. NO.
(818) 354-2984

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year, c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

OBJECTIVES: The purpose of this task is to support asteroid research and the operation of an Asteroid Team within the Earth and Space Sciences Division at JPL. The Asteroid Team carries out original research on asteroids in order to discover, better characterize and define asteroid properties. This information is needed for the planning and design of NASA asteroid flyby and rendezvous missions. The Asteroid Team also provides scientific and technical advice to NASA and JPL on asteroid related programs.

B. PROGRESS: 1) Work on asteroid classification continued and the discovery of two Earth-approaching "M" asteroids last year was published. (The M-class is rare and these are the first found among the near-Earth asteroids to have the spectral albedo characteristic of this class. The derived diameters are about 2 km for both objects.) 2) In the asteroid photometry program we obtained N or Q photometry for more than 50 asteroids, including the two M-earth-crossers. 3) We have initiated a new program to follow-up on IRAS asteroids at the IRTF. 4) Compositional analysis of infrared spectra (0.8 to 2.6μm) of 60 asteroids is continuing. 5) This task supported D. Matson's travel for and participation in the NASA Planetary Astronomy Management and Operations Working Group. 6) This task is supporting the preparation of manuscripts for the publications of the IRAS Asteroid and Comet Catalog.

C. PROPOSED WORK: Over the next year the work on asteroid classification and composition will continue with the analysis of the 60 reduced infrared spectra which we now have at hand. The radiometry program will continue with the reduction of the N and Q bandpass data for the 57 asteroids in order to obtain albedos and diameters. This year the emphasis will shift to IRAS follow-up observations; which includes objects not observed by IRAS and objects with poor or peculiar IRAS data. As in previous years, we plan to give top priority to any opportunities for observing near-Earth asteroids and the support (through radiometric lightcurve observations from the IRTF) of any stellar occultations by asteroids for which occultation observation expeditions are fielded. Support of preparing of IRAS data for publication and of D. Matson for his participation in the NASA Planetary Astronomy Management and Operations Working Group will continue.

D. SUMMARY BIBLIOGRAPHY: Cruikshank, D.P. and Brown, R. H., Organic material on asteroid 130 Elektra, Science 238, 183-184; Bell et al., Composition and size of Apollo asteroid 1984 KB, Icarus 73, 482-486

N89-16668

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Research in Planetary Astronomy (NSG 7323)

PERFORMING ORGANIZATION

Planetary Geosciences Division / Hawaii Institute of Geophysics
2525 Correa Road / Honolulu, HI 96822

INVESTIGATOR'S NAME

Thomas B. McCord

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) *Strategy:* The objective is the continuation of a long-term research program designed to study the composition, structure and processes operating on the surfaces of solar system objects using the Mauna Kea Observatory with techniques and modern instrumentation mostly developed internally. Reflectance spectroscopy and multispectral imaging in the spectral region, 0.3 - 5.0 μm, are the major techniques used, although thermal (10 μm and 20 μm) radiometry are used in some aspects of the research. Of major importance is the active participation of graduate students and young scientists in order to develop new expertise as well as new knowledge and techniques. Some specific projects include *(i)* systematic spectral imaging observations of the Moon, *(ii)* systematic spectral imaging and spectral monitoring of the Martian surface, *(iii)* thermal radiometry of asteroids as part of the IRAS follow-up and other target specific programs, *(iv)* searches for asteroid satellites and dust belts using a stellar coronagraph, and *(v)* studies of circumstellar disks (*e. g.,* ß Pictoris) using a stellar coronagraph.

b) *Progress (7/87 - 6/88):* Progress for each of the programs includes: *(i)* the completion of the reduction of the spectral observations (0.7 μm - 5.0 μm) of the Martian surface obtained at the UH 2.2 meter telescope under our goal to use the near- and mid-infrared to search for compositional and spatial variations of mafic, carbonate and sulfate minerals; *(ii)* completed observations of lunar multi-ringed basins and crater deposits in search of high-Ca spectral anomalies; *(iii)* completed data reduction of an additional 5 asteroids observed by the coronagraphic technique in the search for asteroids satellites and debris clouds; and *(iv)* completed the reduction and calibration of 350 asteroids observed at 10 μm and 20 μm using the NASA IRTF.

c) *Proposed Research:* We plan to continue our efforts in each of the programs described above (Strategy). Some specific goals this year include: *(i)* obtain high-resolution spectral reflectance data of the Martian surface in the wavelength region 2.0 μm - 5.0 μm which will be used to detect and determine clay, sulfate and carbonate abundances and composition; *(ii)* obtain high spatial resolution images of Mars in selected filters between 1.0 μm and 5.0 μm to determine the spatial variability of specific surface minerals and frosts; *(iii)* apply grating (grism)/imaging (CCD) techniques to the study of ferric-ferrous Fe distribution on the surface of Mars; *(iv)* apply grating (grism)/ imaging (CCD) techniques to the identification of and distribution of minerals on the lunar surface; *(v)* obtain 10 μm and 20 μm radiometric measurements simultaneous with 0.55 μm photometry (SUMP at the NASA IRTF) of asteroids in the peculiar Eos asteroid family and other anomalous IRAS asteroids to obtain refined albedos and diameters; and *(vi)* continue the search for satellites and debris clouds around specific asteroids (several William's families suspected of being recent collision events) using the coronagraph.

d) *Summary Bibliography: (7/87 - 6/88)* : This research program provides basic support that increases the productivity of several other research grants. Because of this fact, some of the papers listed were only partially supported by this grant. 3 papers published, 7 submitted.

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Hawke, B.R., P.G. Lucey, and P.D. Spudis, "Impact Structures as Probes of the Lunar Interior", *Meteoritics*, submitted, (1988).

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Roush, T.L., and P.G. Lucey, (1988), "A Search for Water on the Moon at the Reiner Gamma Formation, A Possible Site of Cometary Coma Impact", *Proc. 18th Lunar and Planet. Sci. Conf.*, 397-402.

Spudis, P.D., B.R. Hawke, and P.G. Lucey, "Geology and Deposits of the Lunar Nectaris Basin", *Proc. Lunar and Planet. Sci. Conf., 19th*, submitted (1988).

Spudis, P.D., B.R. Hawke, and P.G. Lucey (1988)., "The Materials and Formation of the Imbrium Basin", *Proc. 18th Lunar and Planet. Sci. Conf.*, 155-168.

N89-16669

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Asteroid and Comet Surfaces

PERFORMING ORGANIZATION

California Space Institute, University of California, San Diego

INVESTIGATOR'S NAME

Lucy-Ann McFadden

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. Strategy: Photometric and spectrophotometric studies of asteroids and comets are in progress to address questions about the mineralogical relationship between asteroids near the 3:1 Kirkwood gap and ordinary chondrite meteorites and between cometary nuclei and the surface of asteroids.

B. Progress: i) The method to convert the measured excess UV flux in the spectrum of 2201 Oljato to column abundance of OH and CN was derived. ii.) Spectral reflectance measurements of large asteroids near the 3:1 Kirkwood gap, which is expected to be the source of ordinary chondrite meteorites, were briefly examined and show no spectral signatures that are characteristic of ordinary chondrite meteorite powders measured in the lab. iii.) A review paper on the physical properties of near-earth asteroids was written for the Asteroids II book. iv) A section in the chapter on the Relationships between comets and asteroids for the Asteroids II book was written. v.) A study of the bare nucleus of comet Neujmin 1 was completed in which its photometric and thermal properties were studied and related to asteroid types. This paper won an award for best physics paper by an employee of SAIC (Campins) in 1987.

C. Anticipated Accomplishments i.) Perform the calculations to quantify potential OH and CN emission in spectrum of 2201 Oljato. Complete the paper on this subject. ii) Perform final data reduction on near-IR reflectance spectra of asteroids near 3:1 Kirkwood gap. Write up the results. iii.) Observe asteroids in comet-like orbits to determine their relationship to comets and other asteroids with CCD spectrometers and Near-IR spectrometers.

D. summary bibliography

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N89-16670

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

The Radial Velocity Search for Extrasolar Planets

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
Space Sciences Building
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Robert S. McMillan

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: We are measuring small changes in the line-of-sight velocities of stars to detect the oscillating reflex acceleration induced by large planets. Our intention is to observe enough stars for a long enough time to be able to make a statement of the probability of planets in a certain range of masses even if we detect no planetary perturbations. To make these measurements of Doppler shift with the required sensitivity, we designed, built, and thoroughly tested a new instrument specifically for this campaign of ground-based planet detection. The instrument is an optical spectrometer for which wavelengths are first calibrated by transmission through a tunable Fabry-Perot etalon interferometer. The intrinsic stability of the etalon and an image-scrambling fiber optic light feed provide great sensitivity to line-of-sight accelerations and immunity to systematic errors.

b. Accomplishments: We now have three years of consistent operation and calibration and are making many observations with uniform procedures every month. Formal observations began in September 1985 and a total of 6445 observations of 21 stars have been made on 241 nights to date (1988 May 27 UT). The interferometer is calibrated about 100 times per night with an accuracy of $\pm$ 6 meters/sec in Doppler shift. The standard deviation of a one-hour exposure on a typical solar-type star of blue magnitude 4.0 is $\pm$ 12 m/s. On a star with B = 5.5 the error is $\pm$ 30 m/s per observation. These random errors "average down" through an observing season, giving adequate accuracy for the search for planets. We already have published discoveries of a 2.2-day oscillation of the radial velocity of Arcturus, three modes of short-period oscillations in Pollux, and non-variability of the radial velocity of Eta Cas A, previously suspected to be a spectroscopic binary. We are also seeing slow velocity variations in some other stars, which is encouraging for the detection of orbital motion.

c. Anticipated Accomplishments: Our data show tantalizing hints of small velocity perturbations which should become definitive after two more years of observing. We propose to continue the observing program for at least another two years, to bring the length of our time series to five years. This is thought to be a minimum duration for finding planets massive enough to cause detectable changes in the Doppler shifts of stars.

d. Publications:

McMillan, R. S., Perry, M. L., Smith, P. H., and Merline, W. J. 1988, "The Optical Fiber Feed of the LPL Radial Velocity Spectrometer", Pub. A. S. P. Suppl. Ser., in press.

McMillan, R. S., and Smith, P. H. 1987, "Nonvariability of the Radial Velocity of Eta Cas A", Pub. A. S. P., 99, 849.

Smith, P. H., and McMillan, R. S. 1987a, "Short Period Oscillations in Alpha Boo, Beta Gem, and Alpha Tau", in Proc. IAU Symp. 132, The Impact of Very High Signal:Noise Spectroscopy on Stellar Physics, in press.

Smith, P. H., and McMillan, R. S. 1987b, "Accurate Accelerometry of Solar-Type Stars", in Proc. 27th Liege International Astrophysical Colloquium, Observational Astrophysics with High Precision Data, (Dordrecht: Reidel), in press.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Occultation Studies of the Solar System
NASA Grant NSG-7603

PERFORMING ORGANIZATION
Lowell Observatory
1400 West Mars Hill Road
Flagstaff, Arizona 86001

INVESTIGATOR'S NAME
Robert L. Millis

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy. Occultations of stars by planets, satellites, planetary ring systems, asteroids, and comets provide valuable opportunities to probe the Solar System in ways otherwise impossible from the surface of the Earth. For example, one can precisely measure the size and shape of objects which are much too small to be resolved directly, accurately map the structure and transparency of ring systems, and detect the faintest trace of an atmosphere. In this investigation, we identify upcoming occultations through wide-ranging computer searches, provide accurate predictions for the more important events, and observe selected occultations with our specially designed portable photmetric equipment.

b. Accomplishments. During the past year, we produced accurate predictions for an occultation of AG+40°0783 by 324 Bamberga on 8 December 1987 and coordinated efforts to observe this event. The occultation was successfully observed at 13 sites including two manned by Lowell Observatory astronomers. We presented a preliminary analysis of the data at the Asteroids II Conference held in Tucson in March 1988. We also have devoted a lot of time to producing an accurate prediction for the 9 June 1988 occultation of a star by Pluto. Prediction of this important occultation is complicated by the presence of Pluto's satellite, Charon. We have worked closely with astronomers at MIT, Lick Observatory, and the U.S. Naval Observatory, in the application of a variety of astrometric approaches to this problem. If the occultation is successfully observed, there will be a major advance in our knowledge of the most distant planet. Finally, Millis, in collaboration with Dr. David Dunham, has recently completed a lengthy review paper on occultation studies of asteroids.

c. Expected Accomplishments. Next year we expect to complete an analysis of existing observations of occultations by the asteroids 47 Aglaja and 324 Bamberga. We expect to participate fully in the analysis of observations of the 9 June Pluto occultation, should we or our collaborators succeed in observing it. Additionally, 1989 will be a banner year for occultation observers, with outstanding occultations involving Saturn, Vesta, Ceres, Kleopatra, Bamberga, and Brixia predicted to occur. We intend to observe most, if not all of these. The Saturn occultation provides an opportunity to probe that planet's rings with a resolution approaching that achieved by the *Voyager* spacecraft. Kleopatra is believed, on the basis of radar observations, to be extremely elongated. Occultation observations can check that result. Vesta is the one remaining asteroid whose mass is well known, but whose size is not. We plan to measure the size and thereby determine Vesta's density, which in turn gives a direct clue to this unusual asteroid's composition.

SUMMARY BIBLIOGRAPHY

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N89-16672

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Lunar and Planetary Studies

PERFORMING ORGANIZATION

Division of Geology and Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

INVESTIGATOR'S NAME

D.O. Muhleman (P.I.), P. Goldreich (Co-P.I.), A.P. Ingersoll (Co-P.I.) and
J.A. Westphal (Co-P.I.)

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

A) This grant supports the core program in planetary astronomy at Caltech under the direction of Professors Muhleman, Goldreich, Ingersoll and Westphal. The research includes observations in the IR, sub-mm, mm and cm wavelengths at national and Caltech observatories with a strong emphasis on integrating the observations with spacecraft data and with models of atmospheric structure, dynamics and chemistry.
B) Muhleman's group have made extensive observations at the VLA of Saturn, Uranus and Neptune which are being interpreted in terms of deep atmospheric structures which are obvious in the 2 and 6 cm maps of Saturn and Uranus. The microwave measurements are one of the few sources of information below the 2 bar level. Ingersoll and Dowling (1988) have used cloud-tracked winds derived from Voyager images to infer the winds at cloud base around the Great Red Spot and white oval BC. The method uses the conservation of potential vorticity, which relates absolute vorticity (an observable) to the pressure thickness of the cloudy layer. Goldreich is investigating the dynamics of narrow rings with postdoctoral fellow, Pierre-Yves Longaretti. Their work has focused on the role of collisional stresses on the precession of the rings, since the Voyager radio science results imply that the previous model based on the ring's self-gravity is not the entire story. In addition Borderies, Goldreich and Tremaine have completed an investigation of the dynamics of the Encke division in Saturn's A ring that is currently being written up.
C) In the coming year, Goldreich intends to prepare for the encounter of Voyager 2 with Neptune by extending his model of the Neptune arcs and by initiating a study of the dynamics of Neptune's satellite system. Westphal will begin a Neptune satellite search program with the Planetary Patrol Telescope on Mauna Kea to try to verify Goldreich's theoretical work. Muhleman and Bruce Betts (a graduate student) have time on the 200-inch to study the IR light curve of the Galilean Satellites to search for correlations with albedo and 3 mm brightness temperatures over the orbits of each. Ingersoll and students will be extending their vorticity study to other latitudes in Jupiter and Saturn's atmospheres. Also, they will try to settle an 8-year-old controversy over the transfer of momentum by eddies into (or out of) the zonal jets. Mark Hofstadter and Muhleman will observe Uranus at the VLA at a wavelength of 6 cm. These data (limb darkening curves and latitude variations) will make it possible to better explore the chemistry of NH_3, H_2O and sulfur compounds in the Uranian atmosphere between 1 bar and 10 bars (or more).

Achterberg, R.K. and A.P. Ingersoll, Vertical structure in quasi-geostrophic models of Jupiter. Bull. *Amer. Astron. Soc.* **19**, 836, 1987; *J. Atmos. Sci.*, in preparation.

Berge, G.L., D.O. Muhleman and R.P. Linfield, Very Large Array observations of Uranus at 2.0 cm. In press *Astron. J.*, 1988.

Berge, G.L., D.O. Muhleman, D. Rudy and R. Lindfield, VLA observations of Uranus at 2.0 cm. Submitted to *Icarus*, 1987.

Dowling, T.E., and A.P. Ingersoll, Potential vorticity and layer thickness variations in the flow around Jupiter's Great Red Spot and White Oval BC. *J. Atmos. Sci.* **45**, 1380-1396, 1988.

Friedson, J. and A.P. Ingersoll, Seasonal meridonal energy balance and thermal structure of the atmosphere of Uranus: A radiative-convective-dynamical model. *Icarus* **69**, 135-156, 1987

Goldreich, P. and C.C. Porco, Shepherding of the Uranian Rings. I. Kinematics. *Astronom. J.* **93**, 724-729, 1987.

Goldreich, P. and C.C. Porco, Shepherding of the Uranian Rings. II. Dynamics. *Astronom. J.* **93**, 730-737, 1987.

Rudy, D., D.O. Muhleman, G.L. Berge, B. Jakosky and P.R. Christensen, VLA Observations of Mars at 2 and 6 cm: The Northern Hemisphere and North Pole Region. *Icarus* **71**, 159-177, 1987.

N89-16673

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE: Submillimeter and Millimeter Observations of Solar System Objects
NASA Grant NGL 05-002-114

PERFORMING ORGANIZATION: Division of Geological and Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

INVESTIGATOR'S NAME
Professor Duane O. Muhleman

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. Planetary atmospheres and satellite surfaces are observed with the three element array at Caltech's Owens Valley Radio Observatory, Caltech's submillimeter telescope on Mauna Kea and at the 12-meter telescope at Kitt Peak. We are primarily interested in spectroscopy of the atmospheres of Venus, Mars and Titan and the continuum structure of Saturn Rings, Galilean satellites, Neptune and Uranus.
B. During the last year we completed a supersynthesis of the Saturn system at 2.8 mm with spatial resolution of 3 arc sec. We just completed a 4-configuration synthesis of Venus in the CO absorption line. We hope to recover the wind patterns in the altitude range from 60 to 100 km where winds have never been measured. Two important questions are being investigated: (1) how high in the Venus atmosphere do the 4-day winds extend and (2) can we produce experiment proof (or disproof) of the subsolar-to anti-solar flow (Dickenson winds) predicted by general circulation models?
C. During the Next year we will reduce and analyze all of the data discussed above, make an even greater effort to measure the CO in the atmosphere of Titan and study the CO distribution in the atmosphere of Mars. The latter requires new observations.

D. Bibliography:

Aperture Synthesis Observations of Saturn and its Rings at 2.7mm Wavelength. T.E. Dowling, D.O. Muhleman and G.L. Berge, *Icarus* 70, 506-516 (1987).

Observations of Mars, Uranus, Neptune, Io, Europa, Ganymede and Callisto at a Wavelength of 2.66 Millimeters. Duane O. Muhleman and Glenn L. Berge. Ready for submission to *Icarus*.

N89-16674

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Physical Processes in Comets

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Ray L. Newburn, Jr.

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: When this program began in 1975 only limited photometry had been carried out on comets at any wavelength and that done had been largely what could be accomplished in single observing runs on bright comets. Program goals were to observe many comets, including faint periodic comets, at a range of heliocentric distances in order to begin to understand the range of behavior among comets and in a given comet during its approach and departure from the Sun. Then a study of the continuum of scattered light from dust was added. something no one else was doing in visible light, in order to measure dust to gas ratios. More recently the value of joint team observations in visible and infrared light has been recognized and utilized as often as possible.

b. Progress: All 1978-82 data has been reanalyzed and 1983-86 data analyzed in the framework of the post-Halley paradigm, covering 25 comets in all. Four observing runs at the IRTF (June, July, Sept., and Jan.) with Hanner produced excellent results on Wilson, Bradfield, P/Klemola, and P/Borrelly and lesser data on other objects, including the last reported IR photometry of P/Halley. The Wilson and Halley data have been reduced and written up for publication, and those on Bradfield and Borrelly are currently in work and being combined with visible light observations from Lick Observatory.

c. Anticipated Accomplishments: Today a complete new approach is being planned, involving 2-dimensional observations in visible and infrared and more realistic non-isotropic, chemical modelling of gases and dust. Solutions will be sought in coming years to the problems of gas evolving from dust, dust fragmenting, non-isotropic emission of dust and gas, non-steady flow of dust and gas, and improved theoretical modelling of chemical processes leading to improved knowledge of composition. Observations will be 2-dimensional whenever possible (CCDs and infrared arrays), improved photometric accuracy sought, and improved chemical modelling utilized in cooperation with the JPL astrochemistry team.

d. Divine, N. and Newburn, R. L. Jr., "Modeling Halley Before and After the Encounters," Astron. Astrophys., 187, 867, (1987).

Hanner, M. S., Newburn, R. L. Jr., et al, "Comet Sugano-Saigusa-Fujikawa (1983V), A Small Puzzling Comet," Astron. J., 94, 1081, (1987).

Newburn, R. L. Jr. and Spinrad, H., "Spectrophotometry of Seventeen Comets. III. Post-Halley Updates Plus Eight Additional Comets., Astron. J. (in typing).

N89-16675

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Imaging Studies of Comets

PERFORMING ORGANIZATION
Laboratory for Astronomy and Solar Physics
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME | TEL. NO.

Malcolm B. Niedner, Jr. (301) 286-5821

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year, c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a.) The Joint Observatory for Cometary Research (JOCR) is jointly run by NASA-GSFC and the New Mexico Institute of Mining and Technology. JOCR emphasizes imaging observations of cometary plasma on the large and small scale, from which data it is hoped that an increased understanding of the comet/solar-wind-IMF interaction will emerge. JOCR is located under dark skies on South Baldy mountain (el. 10,600 feet) near Socorro, NM, and is one of the last truly dark sites in the continental U.S. The principal instrument is a 14-inch "Comet Schmidt" which records an $8^{o}x10^{o}$ field onto 4"x5" plates. A 16" Newtonian/Cass. also exists on site and is presently operational with a CCD detector for filtered observations of the near-nuclear region of comets. JOCR imagery of bright comets since 1973 has resulted in several important published findings concerning cometary plasma structure and solar-wind interactions.

b.) Schmidt camera plates of comet Bradfield were secured on several nights in October 1987. The images of October 20 show the development of a huge bend in the plasma tail travelling several hundred kilometers per second down the tail; the likely solar-wind origin of this event is being explored at the present time. A CCD detector has been successfully installed on the 16" telescope and several non-cometary images have been obtained. Calibration of the CCD is still underway, but high-quality, filtered cometary images should be possible in the near future.

c.) Plans include obtaining CCD photometry of stars along Halley's path for determining Halley's variable ion production rate--apparent in the wide-field Schmidt images--at times of disconnection events; and further development of the 16" Newtonian/Cass. instrument for the post-Halley era, including the purchase of a spectrograph for the CCD and an offset guider. For the Schmidt, we plan to purchase new slow motion paddles and a sensitometer so that plates calibrated for relative intensity can be obtained of future bright comets. **The analysis of the 1987 comet Bradfield plasma-tail transient will continue.**

d.) "Plasma-Tail Activity at the time of the VEGA Encounters", M. B. Niedner and K. Schwingenschuh, Astron. Astrophys., 187, 103-108 (1987).

"A Solar-Wind-Induced Extreme Tail Deformation in Comet Bradfield 1987", D. A. Klinglesmith, M. B. Niedner, and S. N. Shore, B. A. A. S. (Abstract) 1988.

N89-16676

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

CCD Camera System for Cometary Research

PERFORMING ORGANIZATION

Laboratory for Astronomy and Solar Physics
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME | TEL. NO.

R. J. Oliversen | (301) 286-6290

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) The objective is to upgrade the NASA/GSFC 36" telescope instrumentation, primarily with a new CCD camera system, to permit an effective monitoring program of cometary activity by means of narrowband imaging and spectroscopic techniques.
b) We have twice taken delivery of the CCD camera system from Princeton Scientific Instruments and twice returned it within six weeks for repair. During the times we had the camera system in the lab, we measured the instrumental performance of the TEK 512x512 CCD chip (e.g., readout noise, dark current, etc.) and developed the complete operational software for the camera system plus several useful observing and data reduction routines for use at the telescope. The CCD camera system is controlled by an IBM AT computer. The peripheral equipment and software to permit the efficient transfer of large amounts of data to the LASP's computers (VAXs) and subsequent timely reductions are also in place. The Io torus [S II] emission was monitored with a Fabry-Perot scanning spectrometer, in conjunction with the International Jupiter Watch.
c) The CCD camera system will be coupled to a narrowband interference filter imager and a long-slit spectrograph to provide regular and well-calibrated spatial and spectral observations of comets. The CCD instrumentation will be interface to the NASA/GSFC 36-inch telescope which is already equipped with a non-sidereal drive capable of tracking comets. The large dynamic range, low noise characteristics and high quantum efficiency of CCDs overcome the cometary observational difficulties of a large range of intensities and faint extended features. Photometric narrowband images in selected emission lines or bands (e.g., C_2, CN, C_3, [O I], H_2O^+) and the continuum, as well as long-slit spectroscopy will determine gas to dust column density ratios, abundances, production rates, and scale lengths as a function of heliocentric distances. Monitoring of cometary activity on both its pre- and post-perihelion orbital phases will provide information concerning the chemical homogenuity of the nucleus, place tighter constraints on chemical models of the coma, and improve our understanding of the solar wind/radiation interaction with coma and tail structures.
d)

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Infrared Observations of Planetary Atmospheres

PI: Glenn S. Orton (JPL)
Co-I's: Kevin H. Baines,
Jay T. Bergstralh (JPL)

196-41-77-02-55

a. The goal of this research in to obtain infrared data on planetary atmospheres which provide information of several aspects of structure and composition. Observations include direct mission real-time support as well as baseline monitoring preceding mission encounters. Besides providing a broader information context for spacecraft experiment data analysis, observations will provide the quantitative data base required for designing optimum remote sensing sequences evaluating competing science priorities.

b. In the past year, thermal images of Jupiter and Saturn were made near their oppositions in order to monitor long-term changes in their atmospheres. Infrared images of the jovian polar stratospheric hot spots were made with IUE observations of auroral emissions. An exploratory 5-micron spectrum of Uranus was reduced and accepted for publication. Simultaneous measurements of CH4 and CH3D will have been made (July 1988) to determine this ratio in Neptune's atmosphere. An analysis of time-variability of temperature and cloud properties of the jovian atmosphere was made and submitted for publication in a NASA SP. Development of geometric reduction programs for imaging data was initiated for the Sun workstation. Near-infrared imaging observations of Jupiter were reduced and a preliminary analysis of cloud properties made. The first images of the full disk of Jupiter with a near-infrared array camera were acquired. Narrow-band (10 cm-1) images of Jupiter and Saturn were obtained with acousto-optical filters.

c. During the next year, monitoring of Jupiter and Saturn will continue with correlative visible and ultraviolet work. Observation of Uranus and Neptune at higher spectral resolution in the 7- to 17-micron region will be attempted in selected spectal regions to determine compositional constraints. Calibration of central meridian scans of Jupiter wil be finished and of images of Jupiter and Saturn initiated. Observations will continue in the near-infrared region with the JPL imaging spectro-polarimeter, concentrating on the disk of Saturn.

d. Publications are shown on the next page.

Publications

Reviewed Contributions:

G. Orton, D. Aitken, P. Roche, C. Smith, J. Caldwell and R. Snyder 1987. The spectra of Uranus and Neptune at 7-14 and 17-23 microns. Icarus 70, 1-12.

R. Halthore, J. Caldwell, G. Orton, and J. Bergstralh 1988. Infared polar brightening on Jupiter IV. Spatial properties of methane emission. Icarus 74, 331-339.

R. F. Beebe, G. S. Orton , and R. A. West. 1988. Time-variability of clouds and temperatures: An observational perspective. In Time-Varible Phenomena of The Jovian System. (Belton, Hunt, and West, Eds.) NASA Special Publication.

G. S. Orton and C. D. Kaminski 1987. An exploratory 5-micron spectrum of Uranus. Icarus. In press.

Abstracts:

Baines et al. 1987. Stratospheric aerosols in the Great Red Spot and South Polar Region on Jupiter. Bull. Amer. Astron. Soc. 19. 827.

G. S. Orton and C. D. Kaminski 1987. The low-resolution 5-micron spectrum of Uranus. Bull. Amer. Astron. Soc. 19, 852.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radar Investigation of Asteroids and Planetary Satellites

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

INVESTIGATOR'S NAME

Steven J. Ostro

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: Radar reconnaissance of near-Earth asteroids, mainbelt asteroids, the Galilean satellites, the Martian satellites, and the largest Saturnian satellites, using the Arecibo 13-cm and the Goldstone 3.5-cm systems. Measurements of echo strength, polarization, and delay/Doppler distribution of echo power provide information about dimensions, spin vector, large-scale topography, cm-to-m-scale morphology, and surface bulk density. The observations also yield refined estimates of target orbital elements.

b. Accomplishments: Radar signatures have been measured for 31 mainbelt asteroids and 16 near-Earth asteroids since this task began eight years ago. The dispersion in asteroid radar albedoes and circular polarization ratios is extreme, revealing huge differences in surface morphologies, bulk densities, and metal concentration. For the most part, correlation between radar signature and VIS/IR class is not high. Many near-Earth asteroids have extremely irregular, nonconvex shapes, but some have polar silhouettes that appear only slightly noncircular. The signatures of 1627 Ivar, 1986 DA, and the ~180-km mainbelt asteroid 216 Kleopatra suggest bifurcated shapes. Observational milestones during 1987-88 include (i) the first definitive measurement of Io's dual-polarization, 13-cm radar signature; (ii) highly successful, initial radar studies of two near-Earth objects: 1981 Midas at 13.5-cm and the rendezvous-mission candidate 3757 (1982 XB) at 13-cm; (iii) the first 3.5-cm radar detection of Callisto; (iv) the first 13-cm radar observations of the icy Galilean satellites since 1979, with several times the SNR available then; and (v) a series of time-delay-resolved observations of the mainbelt asteroid 654 Zelinda with a" range" precision of 10 km.

c. Anticipated Accomplishments: 1) The first radar observations of Phobos and Deimos. 2) Extensive 13-cm and 3.5-cm investigations of all four Galilean satellites during the most favorable Jupiter opposition of the next ten years. 3) High-resolution delay/Doppler imaging of asteroids 1685 Toro, 1580 Betulia, and 1980 PA.

RADAR INVESTIGATION OF ASTEROIDS AND PLANETARY SATELLITES

196-41-73-06-55 S. J. OSTRO, PI

MAY 1987 - JUNE 1988

Publications:

Ostro, S. J.: Physical Properties of Asteroids from Radar Observations. The Evolution of the Small Bodies in the Solar System (M. Fulchignoni and L. Kresak, eds.), Soc. Italiana di Fisica, Bologna, Italy, 131, 1987.

Yeomans, D. K., Ostro, S. J., and P. W. Chodas, P. W.: Radar Astrometry of Near-Earth Asteroids. Astron. J. 94, 189, 1987.

Ostro, S. J. (1987). Benefits of an Upgraded Arecibo Observatory for Radar Observations of Asteroids and Natural Satellites. Proceedings of the Arecibo Upgrading Workshop (J. H. Taylor and M. M. Davis, eds.), National Astronomy and Ionosphere Center, Box 995, Arecibo, PR 00613; 233, 1987.

Ostro, S. J., Connelly, R., and Belkora, L.: Asteroid Shapes from Radar Echo Spectra: A New Theoretical Approach. Icarus 73, 24, 1988.

Ostro, S. J.: Radar Observations of Asteroids. Chapter in Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), Univ. of Arizona Press, accepted, 1988.

Ostro, S. J., Yeomans, D. K., Chodas, P. W., Goldstein, R. M., Jurgens, R. F., and Thompson, T. W.: Radar Observations of Asteroid 1986 JK. Submitted to Icarus, 1988.

N89-16679

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Atmospheric and Surface Compositional Studies of Mercury and the Moon.

PERFORMING ORGANIZATION
Space Science Branch
Solar System Exploration Division
Space and Life Sciences Directorate
NASA Johnson Space Center, Houston, TX 77058

INVESTIGATOR'S NAME | TEL. NO.
Potter, A. E. 713-483-5061

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year. c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy of Investigation: The atmosphere of the Moon and Mercury will be studied by means of high resolution spectroscopy of sodium and potassium resonance line emissions. The variation of metal vapor abundances with time, and with location will be measured with a view to understanding the origin and evolution of these elements in the atmospheres of the Moon and Mercury. Infrared spectroscopic measurements will be made of Mercury to determine the surface mineralogy, predicated on the availability of the Kuiper Airborne Observatory and the KPNO infrared CCD array.

b. Prior Accomplishments: During the past year, an excellent series of measurements were completed of the spatial distribution of sodium on Mercury. Sodium was found to be concentrated at the polar regions, and to be displaced towards the terminator by solar radiation pressure. Sodium and potassium were discovered in the atmosphere of the Moon. The ratio of sodium to potassium approximates that of the lunar regolith. Thermal infrared measurements of Mercury showed that the Christiansen peak was located shortwards of 8 microns, which indicates an acidic mineralogy.

c. Planned Accomplishments: The sodium and potassium atmospheres of the Moon will be mapped. The variation of scale height and abundance as a function of latitude and longitude relative to the subsolar point will be measured to the extent possible with telescope time made available for this purpose. Work will continue on measurement of the abundance and spatial distribution of the sodium and potassium atmosphere of Mercury. Infrared measurements of Mercury in the 6-8 micron region and the 2-4 micron region will be done, predicated on the availability of instrumentation needed for these measurements

d. Summary Bibliography:

Potter, A. E., and Morgan, T. H. 1987, "Variation of Sodium on Mercury with Solar Radiation Pressure," Icarus, 71, 472.

Morgan, T. H., Zook, H. A., and Potter, A. E. 1988, "Impact Driven Supply of Sodium and Potassium to the atmosphere of Mercury", Icarus, 74, to appear.

Hunten, D. M., Morgan, T. H., and Shemansky, D. E. 1988, "Atmosphere of Mercury" In Mercury (C. Chapman and F. Vilas Eds.) University of Arizona Press, Tucson (to be pub.)

Morgan, T. H., Zook, H. A. and Potter, A. E. 1988, "Production of Sodium and Potassium from the Lunar Regolith", Lun. Plan. Sci. Conf. XIX, 806-807

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Fabry-Perot Ground-Based Observations of Comets and the Jupiter Plasma Torus

PERFORMING ORGANIZATION

Physics Department
University of Wisconsin
Madison, WI 53706

INVESTIGATOR'S NAME

Frank Scherb, Fred L. Roesler

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: The Wisconsin 150 mm dual etalon Fabry-Perot spectrometer is a powerful instrument for the study of diffuse emission sources such as cometary atmospheres, the Jupiter plasma torus, and various emission nebulae. Since 1985, we have concentrated our efforts on extensive observations of comet Halley and the analysis of the data.

b. Accomplishments: Images of comet Halley in [OI]6300Å emission were analyzed to obtain the spatial distribution of $O(^1D)$ in the cometary atmosphere. The narrow spectral bandpass of the Fabry-Perot (0.2Å) eliminated contamination from terrestrial airglow [OI]6300 and cometary NH_2 lines in the nearby spectrum. The results were modeled to provide photodestruction lifetimes of cometary H_2O and OH, the predominant parents of $O(^1D)$.

The Fabry-Perot was also used in the scanning mode to obtain measurements of [OI]6300 and Balmer alpha (Hα) emissions which were used to determine the H, $O(^1D)$ and H_2O production rates as a function of heliocentric distance, both pre-perihelion and post-perihelion. We have also analyzed our high resolution spectra of the NH_2 (0,8,0) band in the 6300Å region to obtain preliminary values of the NH_2 production rate. Assuming NH_3 is the major parent of NH_2, we find that the abundance ratio NH_3/H_2O is about $(0.12\pm0.04)\%$, assuming thermal equilibrium for the level populations of NH_2.

Scans of the H_2O^+ (0,8,0) band spin doublet at 6158.64Å and 6158.86Å were used to obtain H_2O^+ emission intensities and ion accelerations in the coma and along the ion tail of the comet. The ion acceleration was approximately constant along the tail on each night, but varied from night to night.

c. Anticipated Accomplishments: Much of the imaging data from comet Halley remains to be analyzed. We are now completing the installation of an image processing system on our computer to facilitate this analysis.

K. Magee-Sauer completed her Ph.D. thesis in May, 1988. We are now preparing several papers for submission to Icarus before she leaves in August 1988 for her new position at Bartol Research Foundation.

We have established a collaboration with W. Smyth of AER, who will use an advanced Monte Carlo model of the cometary atmosphere to analyze our Hα and [OI]6300 data.

We have recently acquired a CCD camera from Photometrics, Ltd. We plan to use the new camera with the 150 mm Fabry-Perot to carry out a new series of observations of the

Jupiter plasma torus at Kitt Peak in November-December, 1988.

d. Publications

Magee-Sauer, K., F. L. Roesler, F. Scherb, J. Harlander, and R. J. Oliversen: Spatial Distribution of $O(^1D)$ from comet Halley. Icarus (in press).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Radar Studies in the Solar System

PERFORMING ORGANIZATION

Smithsonian Astrophysical Observatory
Cambridge, MA 02138

INVESTIGATOR'S NAME

Irwin I. Shapiro

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy. Our research is twofold: we (i) develop the ephemerides needed to acquire radar data at Arecibo from observations of various solar-system objects, and (ii) analyze the resultant data to (A) test fundamental laws of gravitation; (B) determine the size, shape, topography, and spin vectors of the targets; and (C) study the surface properties of these objects through their radar scattering and polarization characteristics.

b) Accomplishments. We continued the ongoing program of radar observations in collaboration with our colleagues S.J. Ostro and M.A. Slade (JPL) and D.B. Campbell (Arecibo and Cornell). Ephemerides were prepared, and observations were carried out at Arecibo, for the numbered asteroids 4, 20, 105, 654, 1566, 1981, 2212, 3554, and 3757. All of these were successfully detected except Icarus (1566), from which we had hoped to improve our determination of the Sun's quadrupole moment and a model parameter for testing general relativity. The observing program also included Arecibo observations of Mercury, Venus, and the Galilean satellites of Jupiter. The Mercury observations at Arecibo were all within a week of the epoch of a closure point (same surface position as a previous observation), and one was matched by a near-simultaneous observation at Goldstone.

c) Plans. We will continue our participation in the planetary radar program at Arecibo, which includes plans for more Mercury closure points and near-simultaneous Goldstone-Arecibo observations for inter-system calibration. In the fall of 1988, there will be opportunities to observe not only asteroids and the Galillean satellites, but also Phobos and Deimos, the satellites of Mars. We plan to make a comprehensive determination of Venus' spin vector from two decades of data, including the results from the current apparition.

d) Publications. None

N89-16682

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

A Continued Program of Planetary Study

PERFORMING ORGANIZATION

McDonald Observatory
The University of Texas at Austin
Austin, Texas 78712

INVESTIGATOR'S NAME

Harlan Smith
William Cochran
Laurence Trafton
Edwin Barker
Anita Cochran

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. This program conducts solar system research in support of NASA missions and of general astronomical interest. Investigations of the composition, physical characteristics, and changes in solar system bodies are conducted primarily utilizing facilities of McDonald Observatory, but also utilizing various space vehicles where appropriate.

b. We have made the *first* detection of 2μm H_2 emission from Jupiter's southern auroral zone, and we have confirmed our previous detection of northern auroral emission from Jupiter's H_2 S(1) quadrupole line at 2.12μm. Unlike the previously known 8μm aurorae, this phenomenon can not be thermal in origin. Analysis of Raman scattering in the blue and ultraviolet spectrum of Uranus (2000–5000Å) shows that there must be absorbing aerosol particles in the upper 10 mbar region of the atmosphere. We have obtained spectra of Pluto-Charon in and out of eclipse in the red and near IR. These data confirm that CH_4 is confined to Pluto and absent on Charon. We have predicted that there will be prominent changes in the albedo of Pluto near perihelion as the surface frost layer vanishes and the planet darkens, and later as it reforms and the planet brightens. The fact that this darkening has not yet occurred sets a lower limit on Pluto's atmospheric bulk. The mole fraction of CH_4 in Pluto's surface volatiles near perihelion should be the same as that of the bulk volatile ice. Therefore, the present spectral observations may indicate that CH_4 is the dominant constituent in Pluto's volatile ices and atmosphere. We have completed a study of low-activity comets and have shown that these comets are intrinsically different from normal comets, and that no obvious parameter exists to explain the differences. We have reduced our long-slit CCD observations of Comet Halley and find that the scale lengths for the molecular species CN, C_2, and CH differ with direction within the coma, but the scale lengths of C_3 are symmetric with direction. The non-equilibrium comet chemistry model is almost completely converted from a 1-D Lagrangian to a 1-D Eulerian formulation. Analysis of the rotational structure of the 3360Å NH emission feature in Comet Halley indicates that resonance fluorescence is the dominant physical process in band formation, and that the role of collisions is negligible. This implies that the NH is formed at greater than 3×10^4 km from the nucleus, and that NH_3 is not the direct parent of NH. We have submitted a large body of Giacobini-Zinner and Halley spectroscopic data to the IHW archive. We have started a systematic survey to discover extra-solar planetary systems by searching for periodic radial velocity variations of the central star. We are able to achieve radial velocity precision of 10-20 m s^{-1}, which is sufficient to detect a Jovian planet around a solar type star.

c. The Faint Comet Survey will continue to monitor all comets brighter than 19.5 mag available from McDonald Observatory. Some comets will be available for a second apparition, allowing us to examine their long-term evolution. We will continue mapping the H_2 quadrupole auroral emission from Jupiter and will attempt to discriminate between a fluorescence source and impact ionization. The lingering Pluto-Charon partial eclipses will provide us with additional opportunity to measure the radial extent of the CH_4 atmosphere of Pluto. We will continue our survey for extra-solar planetary systems, and will develop instrumentation to significantly improve our measurement precision.

d) Summary Bibliography

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N89-16683

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLES
Ground-based Spectropolarimetric Studies of the Outer Planets and Titan (NSG-7334)
High Resolution Spectral Imagery for Periodic and New Comets (NAGW-883)

PERFORMING ORGANIZATION

Washington University

INVESTIGATOR'S NAME

Wm. Hayden Smith

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a). Using novel spectropolarimeteric imaging techniques, we have studied the outer planets, Titan, and various comets. b.) In the previous year, we submitted and have now in press or published fourteen papers on studies of comets and planets, as well as instrumentation developments to enhance our observational studies. c). no further work is planned this year as we were not funded for further research. d). see attached pages of papers; published, in press, or submitted.

103. Spectral Differential Imaging Detection of Planets about Nearby Stars, P.A.S.P.,99,1344(1987).

104. Spectral Imagery with an Acousto-Optic Tunable Filter,(with Schempp,W.V.,Conner,C.,and Katzka,P.),P.A.S.P.,99,1335,(1987)

Papers in press:

105. Spatial and Temporal Variations of the NH_3 Abundance and Cloud Structure in the Jovian Troposphere Derived from CCD/Coude Observations (with K.Baines and C.Alexander),Paper.CJ.9,"Time Variable Phenomena in the Jovian System", Flagstaff,1988, in press, NASA SP___.

106. A Holographic Fourier Transform Spectrometer for Astronomical Applications,(with W.Schempp),Applied Optics, accepted,1988.

107. The D/H Ratio for Jupiter (with K.Baines,and W.V.Schempp), Ap.J., ~~accepted~~ Dec. 1 issue, 1988.

108. D/H for Uranus and Neptune, (with K.Baines, W.Schempp, and J.Simon), Ap.J., ~~accepted~~ Dec 1 issue, 1988.

109. Diurnal Observations of H_2 Quadrupole Features in Neptune,(with W.Schempp and K.Baines),Ap.J.,accepted,1988.

110. Measurements of the H_2 4-0 S(0,1, and 2) Features in Jupiter, (with Simon,J.,Schempp,W.V.,and Conner,C.),Icarus,accepted,1988.

111. The 5577 A and 6300 A [O I] Features in Comet Halley, (with W.V.Schempp),Icarus,accepted,1988.

112. Search for K I in the Coma of Comet Giacobini-Zinner during an Apulse,(with W.Schempp,B.Lutz,and D.Lien),P.A.S.P.,accepted,1988.

113. Study of Diffuse Interstellar Bands in Comet Halley,(with W.V. Schempp),Ap.J.,accepted,1988.

114. Spectral Difference Imaging of Substellar Objects, Workshop on the Origin and Evolution of Planetary Systems, STSCI, Baltimore, May 9-11,1988.

Submitted papers:

114. Search for Fluoresence of H_2 in Comet Halley,(with R. Wolstencroft and B.Lutz),P.A.S.P.,submitted,1988.

115. Observations of the H_2 $S_3(1)$ and $S_4(1)$ Transitions in the Atmosphere of Neptune and Uranus,(with K.Baines and W.Schempp), Ap.J.,submitted,1988.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Research at Palomar Observatory in Planetary Astronomy

PERFORMING ORGANIZATION
Division of Physics, Math and Astronomy
California Institute of Technology
Pasadena, CA 91125

INVESTIGATOR'S NAME
B. T. Soifer, P. Goldreich

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy

A wide range of observational studies are carried out to improve our understanding of the bodies of the outer solar system. Using the 200-inch Hale telescope, near-infrared observations are made of Uranus, Neptune, and the Pluto-Charon system. High time resolution occulation observations of the Uranus Ring system are used to study in detail the dynamics of this system. Occulation studies of Neptune are probing this intriguing "ring-arc" system. Occulation observations of the Pluto-Charon system probe the surface properties of these distant bodies. In addition, the plate material of the PSSII survey is being used to search for new comets and asteroids.

b) Accomplishments

We observed one Neptune stellar occulation in July 1987 and completed the analysis of our series of seven separate Neptune occulation observations in conjunction with Nicholson *et al.*, of Cornell. The analysis has shown that a minimum of three ring arcs, at radii ranging from 54,000 Km - 67,000 Km are required to account for the high quality ring events. Current theoretical models can account for these data. This work was submitted for publication. Of two observations scheduled of Pluto-Charon mutual occulations scheduled for the 200-inch, the Charon eclipse event was successfully observed (the other was clouded out). High signal to noise photometry was obtained in the near-infrared at wavelengths sensitive to the surface composition of volatiles known to exist on planetary surfaces, i.e. Water and Methane. These results show substantial change in the reflectivity of the system as Charon is eclipsed, showing that the surfaces of these bodies are substantially different. The search for new comets and asteroids has been carried out with support from this grant, using plate material of the Palomar Sky Survey II. Three new near-earth asteroids and two new comets were discovered in the four month period July-Oct 87 as the survey began regular production.

c) Anticipated Accomplishments

We shall continue the observational programs carried out in the last years. The 8 July 88 stellar occulation by Neptune will be observed to probe the "ring arc" system. We shall also observe the 21 July 88 stellar occulations by Uranus, with time resolution of 10 milliseconds. Several Pluto-Charon eclipse observations will be observed to map the surface composition of the Southern hemispheres of these systems. In addition, the scanning of the PSSII plates will continue.

d) Publications

Hubbard, W. B., Nicholson, P. D., Lellouch, E., Sicardy, B., Brahic, A., Vilas, F., Bouchet, P., McLaren, R. A., Millis, R. L., Wasserman, L. H., Elias, J. H., Matthews, K., and Perrier 1987, *Icarus*, "Oblateness, Radius, and Mean Stratospheric Temperature of Neptune from the August 20 Occulation".

Nicholson, P. D., Cook, M. L., Matthews, K., Elias, J. H., and Gilmore, G. 1987, *A. J.*, submitted.

Nicholson, P. D., McLeod, B. A., Gilmore, G., Buie, M., and Matthews, K. 1987, *A. J.*, in press.

IAU Circulars

4436 1987 OA
4437 1987 PA
4446 1987 QA
4448 Comet Helin (1987w)
4449 Comet Helin (1987w)
4472 Comet Mueller (1987a1)
4480 Comet Mueller (1987a1)
4495 1982 XB

N89-16685

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Spatially Resolved Quantitative Sprectroscopy of Comets

PERFORMING ORGANIZATION

Department of Astronomy
University of California
Berkeley, California 94720

INVESTIGATOR'S NAME

Hyron Spinrad

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

(a) Strategy: Because of their temporal and spatial variations, modern ground-based studies of comets within ~ 4 A.U. of the sun are observationally demanding tasks. Over the years, we have attempted resolved spectroscopy of comets covering a wide range of intrinsic luminosity. Recently my group has developed spectral and direct-imaging procedures to detect weak ion tails submerged into the comae of even fairly faint comets.

(b) Accomplishments: Although the last year was devoid of any really bright comet, re-analysis of older dust and gas production data with the benefit (hindsight) of the 1986 P/Halley apparition has been almost completed (with R.L. Newburn). The main changes are that the nucleus does make a significant contribution to continuum light, and that the gravity effect in the dust escape velocity is somewhat larger than previously assumed.

On the direct observational side, spectral studies of 1987's Comet Bradfield show it to be qualitatively carbon-rich, at least in the outer coma ratio of CO+ and CO_2+, compared to H_2O+ with respect to Halley at similar heliocentric distances.

(c) Anticipated Accomplishments: We are just beginning our observational study of comet P/Tempel-2 (with Wehinger, Wyckoff, and Belton at KPNO and our usual group at Lick Observatory). The [OI] λ6300 line has just been (weakly) detected (May 12, 1988), so water production has commenced (r = 1.89 A.U.), despite the "puny" appearance of the cometary coma on that date.

(d) Publications (1987/88):

1. Belton, M.J.S., Spinrad, H., Wehinger, P.A., Wyckoff, S., and Yeomans, D.K., 1987, Astron. & Ap. 187, 569, The Spectral Behavior of P/Halley at Large Heliocentric Distance in Light of the Giotto/Vega Results.

2. Hanner, M.S., Newburn, R.L., Spinrad, H., and Veeder, G.J., 1987, Astron. J. 94, 1081, Comet Sugano-Saigusa-Fujikawa (1983V) -- A Small, Puzzling Comet.

3. Spinrad, H., Ann. Revs. Astron. Astrophys. 1987, 25, 231, Comets and Their Composition.

4. Wyckoff, S., Tegler, S., Wehinger, P.A., Spinrad, H., and Belton, M.J.S., 1987, Ap.J. 325, 927, Abundances in Comet Halley at the Time of the Spacecraft Encounters.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

The Evolution of Young Stellar Object Disks and Their Environment

PERFORMING ORGANIZATION
Five College Astronomy Department
Univeristy of Massachusetts, GRC TWR B 517 G
Amherst, MA 01003

INVESTIGATOR'S NAME

Stephen E. Strom

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: By carrying out direct imaging and spectroscopic observations of young, pre-main sequence stars in nearby molecular clouds we have begun:

- to define the frequency with which disks of ~ solar system size and mass form around young stars, and to understand the timescale for disk evolution;
- to characterize the early radiation (ultraviolet and kev particle) environment of circumstellar disks through study of the evolution of stellar winds, wind/disk interactions and the uv and optical emission characteristics of young stars;
- to understand the evolution of the solid and gaseous constituents of disks through observations of absorption features in circumstellar gas, broad emission features produced by organic compounds on grain surfaces, and absorption features (e.g. ice) produced. in grain mantles.

These programs offer the possibility of relating results from astrophysical studies of the environment of newly-formed stars to the record of planet formation preserved in the solar system.

b. Accomplishments:

We completed a spectroscopic survey of 30 T Tauri stars with ages ranging from ~2×10^5 to 3×10^7 years. From analysis of [O I] and [S II] emission lines, we conclude that all but two of the stars in our sample are surrounded by optically opaque disks of dimension ~50 au. The two remaining objects show evidence consistent with partial disk clearing (at an age ~3×10^6 yr).

R and I band CFHT observations yielded detections of disks of dimension ~100 au surrounding 5 additional T Tauri stars.

Analysis of the spectra of low mass young stars of the FU Ori class provide *kinematic* evidence of accretion disks through detection of a correlation between observed absorption line width and the lower excitation potential of the transition; low excitation lines formed in the cooler, outer parts of the disk are narrower than their high excitation counterparts.

c. Anticipated Accomplishments:

We expect to complete an analysis of the infrared emission properties of a large (~ 60) sample of low mass young stellar objects which will permit us to characterize the dependence of disk dust mass on the age of the parent star and to place astrophysical limits on the epoch of disk clearing.

A Study of the Morphology and Kinematics of the Dense Gas Associated with Star-Forming Regions," 1986, Ap.J., 308, 134 - with M.C. Heyer, R.L. Snell, P.F. Goldsmith, K.M. Strom, G.L. Grasdalen, R.W. Capps and D. Thompson.

Forbidden Line and Hα Profiles in T Tauri Star Spectra: A Probe of Anisotropic Mass Outflows and Circumstellar Disks, 1987 Ap. J. 321, 473 - with S. Edwards, S. Cabrit, I. Heyer, K.M. Strom and E. Anderson.

CS Observations of L1551: No Rotating Disk, 1987, Ap. J. 317, L95 - with G.H. Moriarty-Schieven, R.L. Snell and G.L. Grasdalen.

Images of Star Forming Regions. II. The Circumstellar Environment of L1551 IRS 5, Astronomical Journal, submitted July 1987, - with B. Campbell, S.E. Persson and G.L. Grasdalen.

The Magnetic Field Geometry in the Vicinity of HH7-11/HH12 and HH33/HH40, A. J., (in press; December, 1987), - with M.H. Heyer and K.M. Strom.

Luminosity Excesses in Low Mass Young Stellar Objects: A Statistical Study, Astronomical Journal, submitted August, 1987, - with K.M. Strom, S.J. Kenyon and L. Hartmann.

A Detailed Study of The Lynds 1551 Star Formation Region, Astrophysical Journal, submitted June, 1987, - with J.T. Stocke, P.M. Hartigan, K.M. Strom, E.R. Anderson, L.W. Hartmann and S.J. Kenyon.

Energetic Winds and Circumstellar Disks Associated with Low Mass Young Stellar Objects, 1987, "NATO Advanced Study Institute: Galactic and Extragalactic Star Formation: ed. R. Pudritz and M. Fich (Dordrecht: Reidel; Holland) with K.M. Strom and S. Edwards.

Energetic Winds Associated with Young Stellar Objects 1987, "Fifth Cambridge Symposium on Cool Stars" ed. J. L. Linsky and R. Stencel Springer-Verlag (in press).

The Magnetic Evolution of the Taurus Molecular Clouds. I. Large-Scale Properties, 1987, - with M.H. Heyer, F.J. Vrba, R.L. Snell, F.P. Schloerb, P.F. Goldsmith, and K.M. Strom.

Energetic Winds from Low Mass Young Stellar Objects, ed. Springer-Verlag, in press (1987), with S. Edwards.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

ASTEROID SHAPES AND POLE ORIENTATIONS FROM VISUAL AND INFRARED PHOTOMETRY

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

INVESTIGATOR'S NAME

Edward F. Tedesco

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. **STRATEGY**: To obtain visual and infrared lightcurves of Pluto-Charon mutual eclipse event lightcurves and to analyze them to derive models of the Pluto-Charon system, including separations, relative sizes, some orbital parameters, system density, and an albedo map of the hemisphere of Pluto facing Charon.

b. **ACCOMPLISHMENTS**: We have obtained observations of Pluto-Charon mutual events with the Palomar 1.5 and 5-meter, Kitt Peak 1.3-meter, and NASA IRTF 3-meter telescopes. IRAS survey observations of Pluto were combined with the results of our eclipse models to show that the thermal flux observed by IRAS cannot be explained using the standard thermal model for atmospherless solar system bodies but can be explained if Pluto behaves as an isothermal body, e.g., as would be the case if it had a thermally significant atmosphere (Tedesco *et al.*, 1987). A water frost spectrum of Charon was obtained (Buie *et al.*, 1987) and IR lightcurves of two asteroids were used to demonstrate that their visual lightcurves were due primarily to their irregular shapes (Lebofsky *et al.*, 1988).

c. **ANTICIPATED ACCOMPLISHMENTS**: We will make additional visual and infrared mutual event lightcurve observations, develop second order eclipse and infrared models, publish the observational results from the previous three years, hold a fourth Pluto Workshop at the 1988 DPS meeting, and continue coordination of the international campaign and publication of the Pluto newsletter.

d. **PUBLICATIONS:**

Buie, M.W., Cruikshank, D.P., Lebofsky, L.A., and Tedesco, E.F. (1987). Water frost on Charon. *Nature* **329**, 522-523.

Lebofsky, L.A., Greenberg, R., Tedesco, E.F., and Veeder, G.J. (1988). Infrared lightcurves of asteroids 532 Herculina and 45 Eugenia: Proof of the absence of significant albedo markings. *Icarus*, in press.

Tedesco, E.F., Veeder, G.J., Dunbar, R.S., and Lebofsky, L.A. (1987). IRAS constraints on the sizes of Pluto and Charon. *Nature* **327**, 127-129.

N89-16688

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Infrared Imaging of Comets

PERFORMING ORGANIZATION

NASA George C. Marshall Space Flight Center
Huntsville, AL 35812

INVESTIGATOR'S NAME

Charles M. Telesco

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: Thermal infrared imaging of comets provides fundamental information about the distribution of dust in their comae and tails. Our imaging program at NASA MSFC uses a unique 20-pixel bolometer array that we have developed to image comets at 8-30 μm. These images provide the basis for (i) characterizing the composition and size distribution of the particles, (ii) determining the mass-loss rates from cometary nuclei, and (iii) describing the dynamics of the interaction between the dust and the solar radiation.

b. Accomplishments: Since our array became operational in 1985 we have produced at the Wyoming Infrared Observatory and the NASA Infrared Telescope Facility a unique series of IR images of comets Giacobini-Zinner (GZ), Halley, and Wilson. That of GZ was the first groundbased thermal image ever made of a comet and was used to construct, with visible observations, an albedo map. Those data and dynamical analyses showed that GZ contained a population of large (~ 300 μm), fluffy dust grains that formed a distinct inner tail. The accumulating body of images of various comets has also provided a basis for fruitfully intercomparing comet properties. For example, GZ and Halley were observed, at identical earth-comet-sun geometries, to have very different appearances, implying important differences in the dust size distributions. We have also taken advantage of the unique capabilities of our camera to resolve the inner, possible proto-planetary, disk of the star β Pictoris; while not a comet research program, that study is a fruitful additional application of our array to solar system astronomy.

c. Anticipated Accomplishments: We are currently involved in further detailed modelling of the dust distributions in comets using dynamical analyses developed through extensive collaboration. We are also continuing our regular program of 8-30 μm imaging, with the comet Tempel 2 being our primary object for the fall of 1988.

d. Publications

Campins, H., Telesco, C. M., Decher, R., and Ramsey, L. D.: Thermal Infrared Imaging of Comet P/Halley. Astron. Astrophys. 187, 601, 1987.

Decher, R., Telesco, C. M.,Golisch, W. F., Campins, H.: Comet P/Tempel 2. IAU Circular 4580, 1988.

Hammel, H. B., Telesco, C. M., Campins, H., Decher, R., Storrs, A. D., Cruikshank, D. P.: Albedo Maps of Comets P/Halley and P/Giacobini-Zinner. Astron. Astrophys. 187, 695, 1987.

Telesco, C. M., Becklin, E. E., Wolstencroft, R. D., and Decher, R.,: Resolution of the Circumstellar Disk of β Pictoris at 10 and 20 μm. Nature (in press).

N89-16689

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY OPTICAL AND INFRARED IMAGING

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME	TEL. NO.
TERRILE, R. J.	(818) 354-6158

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year, c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

A. OBJECTIVES: The purpose of this investigation is to obtain and analyze high spatial resolution CCD coronagraphic images of extra-solar planetary material and solar system objects. These data will provide information on the distribution of planetary and proto-planetary material around nearby stars leading to a better understanding of the origin and evolution of the solar system. Imaging within our solar system will provide information on the current cloud configurations on the outer planets, search for new objects around the outer planets, and provide direct support for Voyager, Galileo, and CRAF by imaging material around asteroids and clouds on Neptune.

B. ACCOMPLISHMENTS: Over the last year this program acquired multispectral and polarization images of the disk of material around the nearby star Beta Pictoris. This material is believed to be associated with the formation of planets and provides a first look at a planetary system much younger than our own. Preliminary color and polarization data suggest that the material is very low albedo and similar to dark outer solar system carbon rich material. A coronagraphic search for other systems is underway and has already examined over 100 nearby stars. Coronagraphic imaging provided the first clear look at the rings of Uranus and albedo limits for the ring arcs around Neptune.

C. PROPOSED RESEARCH: A survey of the nearby stars will be continued and data will be examined more deeply to provide limits on the probability of circumstellar material around stars and to understand the morphology of young planetary systems. Further imaging of the Beta Pictoris system is planned to obtain polarization data as a function of color. These data will allow a measurement of the particle size distribution of dust in the disk. Coronagraphic imaging of the outer planets, asteroids and star forming regions will continue to provide support for ongoing missions such as Voyager, Galileo, CRAF, Cassini and CIT.

D. SUMMARY BIBLIOGRAPHY: 4 abstracts published. Smith, B. A. and Terrile, R. J. (1987) "The Beta Pictoris Disk: Recent Optical Observations." Bull. Amer. Astron. Soc., 19, 829; Baines, K. H., Bergstralh, J. T., Orton, G. S., Terrile, R. J., Sepikas, J. and West, A. (1987) "Stratospheric Aerosols in the Great Red Spot and the South Polar Region On Jupiter." Bull. Amer. Astron. Soc., 19, 827.

N89-16690

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

PLANETARY FABRY-PEROT SPECTROSCOPY

PERFORMING ORGANIZATION

JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91109

INVESTIGATOR'S NAME	TEL. NO.
Trauger, J. T.	(818) 393-0509

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year. c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Application of high spectral resolution, Earth-based Fabry-Perot spectroscopy to the study of planetary atmospheres, for which current topics are outer planet HD and H_2 spectra (atmospheric structure, D/H ratio), Mars CO_2, CO, O_2, and H_2O spectra (atmospheric photochemistry), Venus H_2O and HDO (was Venus wet?), associated laboratory spectroscopy (especially H_2 overtone bands, HDO). Monochromatic CCD imaging photometry of the Jovian nebula, with images taken in rapid sequence among the diagnostic spectral lines of ionized sulfur species, providing self-supporting snapshots of the Jupiter/Io plasma conditions (spatially resolved electron and ion densities and temperatures), covering the post-Voyager period from 1981 and leading up to the Galileo tour in the early 1990s. High spectral resolution Fabry-Perot/CCD imaging of comets (OI, CI, and H_2O^+ velocity maps and spatial distributions), and Io's charge exchanged neutral jet (direct probe of Io atmospheric structure).
b. Development of data base analysis software to support microVAX-optical disk data archive for F-P/CCD images and planetary spectra. MicroVAX II/Alliant FX-1/Raster Technologies image processing hardware available. Jovian nebula images data base (1980-1986) compiled and data archived to optical disk. Analysis of simultaneous ground-based and IUE observations of Jovian nebula (1981-1985) initiated with T. Skinner. Analysis of Doppler-resolved image sequences (data cubes) of Io sodium neutrals to isolate diverse collision processes near Io, a sensitive probe of the physical interaction of the nebula and the neutral atmosphere of Io. Radiative transfer programs for outer planet spectral line formation ported to Alliant FX-1, with J. Bergstralh and H. Hammel.
c. Analysis of existing data and development of data reduction techniques will continue. New observations focusing on the plasma interactions with the Io atmosphere will be carried out, at least in part in collaboration, with N. Schneider. Reduction of existing Jupiter/Io plasma data, with Caltech graduate student K. Stapelfeldt. Preparations will be made for Mars photochemistry observations, with D. Crisp. Laboratory spectroscopy of H_2 overtone bands at high spectral resolution are in progress, with data analysis to be carried out, with M. Mickelson and students. Modelling of Io atmosphere--neutral sodium phenomena, with H. Garrett. Completion of several papers (outer planet HD/H_2, outer planet H_2 profiles, Io atmosphere collision processes, Jovian nebula).
d. None.

N89-16691

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Planetary Astronomy and Supporting Laboratory Research

PERFORMING ORGANIZATION

Ames Research Center
Moffett Field, CA 94035

INVESTIGATOR'S NAME

Valero, F.P.J.

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Justification: To obtain from laboratory measurements the molecular parameters needed to interpret observations of planetary and cometary spectra, and to develop the analytical and computational techniques to interpret the observed spectra in terms of planetary atmospheres including solids and cometary ices. The gas phase molecular parameters measured include the intensities and half-widths of vib-rotational lines, total intensities of absorption bands, temperature dependencies, and absorption and pressure parameters in random-band models of absorption bands. Computation of line shapes of H2 quadrupole lines from quantum mechanical first principles for comparison with laboratory data and use in modeling of planetary atmospheres. The solid phase measurements include band profile and quantitative intensity measurements and dependence on composition as well as thermal and photolytic processing which mimic the particular astrophysical environments.
b. Accomplishments: Work on GeH4, PH3, CH3D have made significant progress. A paper on the GeH4 results has been submitted for publication and results on CO2, PH3 and CH3D will be reported at the Prague Spectroscopy Conference in September 1988. In the laboratory numerous spectra of CH3D, CO2, GeH4 have been obtained and the required safety measures for levelling of PH3 are being implemented.
c. Plans: The spectra of PH3 will be obtained and work on CH3D and GeH4 will be extended. The modeling effort on Titan's Spectrum will continue in the 1.1 to 2.6 um region.
d. Publications: "Determination of Ao for CH3D from Perturbation-Allowed Transitions" C. Chackerian et al. Jour. Mol. Spect. 117, 355, 1986. "Absolute Line Strengths of PH3 Gas near 5/um" R.W. Lovejoy et al. 109, 246 (1985). "Intensity Measurements of Individual Lines and Manifolds in the Spectrum of the 5 Micron Fundamental Band of Germane" L.P. Giver and C. Chackerian, (submitted) preparation. Line lists on tapes: (include E, Nu and S). Nu3 Band CH3D atmos. Geisa, AFGL-Several CO2 bands AFGL. "Foreign Gas Collision Broadening of the Far Infrared Spectrum of Water Vapor" S.D. Gasster, C.H. Townes, D. Goorvitch and F.P.J. Valero. Jour Opt. Soc. Am. B,

C-3

N89-16692

Title: PHYSICAL PROPERTIES OF ASTEROIDS

Performing Organization: Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109

Investigator's Name: Glenn J. Veeder

A. STRATEGY:

Infrared photometry at 1.2, 1.6 and 2.2 μm provides a relatively rapid and accurate method for the classification of asteroids and is important for comparison with laboratory measurements of meteorites and other possible compositional analogues. Extension beyond the visual is especially useful for minerals which have strong characteristic infrared colors such as olivine in the A class asteroids. Radiometry at long infrared wavelengths is important for deriving basic physical parameters (via thermal models) such as size and albedo which in turn enables the conversion of relative colors to absolute reflectances. In particular, albedos are the only way to distinguish among the otherwise ambiguous E, M and P classes of asteroids.

B. ACCOMPLISHMENTS:

We obtained JHK and/or N infrared observations of 15 asteroids at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea in 1987. We have completed the analysis of 22 Aten, Apollo and Amor asteroids. Our results include albedos and diameters for these objects as well as the identification of the first known class M and class E near-Earth asteroids. The "standard" thermal model appears to be inadequate for some of these small asteroids because of their coarse regolith so we have therefore constructed a rotating thermal model for such asteroids. We have identified a subtle systematic difference between the sub-populations of large and small IRAS asteroids as well as several anomalous objects. We also participated in an IRTF sub-micron photometer (SUMP) engineering run.

C. ANTICIPATED ACCOMPLISHMENTS:

We are now reducing JHK photometry from our survey of the main belt. We will initiate a mini-survey of the Eos family and follow-up selected unusual IRAS asteroids. From this work, we expect to examine whether Eos asteroids are related to the parent bodies of ordinary chondritic meteorites. We will exploit the new SUMP facility by developing the capability to derive accurate visual/infrared colors. SUMP will allow us to eliminate uncertainties due to large lightcurve variations of the irregular near-Earth asteroids. This sub-micron system will also permit us to refine our thermal models in order to investigate the metallic phase in the regolith of some asteroids.

D. PUBLICATIONS

Tedesco, E. F. and Gradie, J. (1987), Discovery of M-class objects among the near-Earth asteroid population. *Astron. J.*, **93**, 738.

Veeder, G. J., M. S. Hanner and D. J. Tholen (1987), The nucleus of Comet P/Arend Rigaux. *Astron. J.*, **94**, 169.

Veeder, G. J., D. L. Matson, E. F. Tedesco, L. A. Lebofsky and J. C. Gradie (1987), Radiometry of Deimos. *Astron. J.*, **94**, 1361.

Veeder, G. J., M. S. Hanner, D. L. Matson, E. F. Tedesco, L. A. Lebofsky and A. T. Tokunaga, Radiometry of near-Earth asteroids. Submitted to *Astron. J.*

N89-16693

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Compositional Studies of Primitive Asteroids

PERFORMING ORGANIZATION
Space Science Branch
Solar System Exploration Division
Space and Life Sciences Directorate
NASA - Johnson Space Center, Houston, TX 77058

INVESTIGATOR'S NAME | TEL. NO.

Vilas, F. 713-483-5056

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year, c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy of Investigation: The composition of primitive asteroids and their relationship to satellites in the solar system will be studied by analyzing existing narrowband CCD reflectance spectra, acquiring additional spectra of asteroids and small satellites in the 0.5 - 1.0 um spectral range, and exploring possibilities for obtaining compositional information in the blue-UV spectral region. Comparison with laboratory spectra of terrestrial chlorites and serpentines (phyllosilicates) and the clay minerals found in carbonaceous chondrite meteorites will continue.

b. Prior Accomplishments: During 1987, narrowband CCD reflectance spectra of 17 additional asteroids were acquired. These spectra and spectra of 34 other asteroids have been used primarily for two studies: weak absorption features similar to those due to Fe^{2+} and Fe^{2+} - Fe^{3+} transitions in iron oxides found in terrestrial chlorites and serpentines and carbonaceous chondrites have been identified in some primitive asteroid spectra. There is a first indication that asteroids grouped by heliocentric distance show similar weak absorption features. Nonparametric statistics are being applied to test the hypothesis of discrete remnants of a gradation in composition of outer-belt asteroids will be tested.

c. Planned Accomplishments: The implications for formation of primitive solar system materials will be addressed through the study of the weak absorption features in the existing CCD reflectance spectra of primitive asteroids. The data base of asteroid spectra will be enlarged. CCD reflectance spectra of small satellites in the solar system (Phobos and Diemos are targetted, because of the presumed C-class broadband photometry) will be acquired.

d. Summary Bibliography:

Vilas, F., Gaffey, M., McFadden, L., King, T. (1986) "A Search for Weak Absorption Features in CCD Reflectance Spectra of Primitive Asteroids", BAAS, v. 18, 796.

Vilas, F., and McFadden, L. (1987) "New CCD Reflectance Spectra of Outer Belt Asteroids", BAAS, v. 19, 825.

Vilas, F. and McFadden, L. (1987) "1 Ceres: Weak Absorption Features Between 0.53 - 0.6 um", BAAS, v. 19, 825.

N89-16694

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE
Passive Microwave Remote Sensing of Asteroids Using the VLA

PERFORMING ORGANIZATION

Geophysics Branch (Code 622)
Goddard Space Flight Center
Greenbelt, MD 20771

INVESTIGATOR'S NAME	TEL. NO.
William J. Webster, Jr.	301-286-4506

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Precise flux density measurements made with the Very Large Array (VLA) of the National Radio Astronomy Observatory will be used to define the microwave continuum spectra of asteroids. These spectra will be inverted in order to estimate the near-surface bulk properties (radii, roughness, composition) independent of previous optical or infrared spectroscopy.

b. The results on 15 Eunomia and 704 Interamnia have been published. The paper on 1 Ceres has been published in the AJ. A paper on the simple models of asteroid radio spectra has been published in the Publications of the Astronomical Society of the Pacific. Preliminary analyses of 2 Pallas, 4 Vesta and 10 Hygeia have been completed. A review chapter for Asteroid II has been drafted.

c. High spatial resolution 2 cm observations of 1 Ceres and 2 Pallas will again be attempted. Previous data have been unsuitable for highest resolution mapping due to adverse weather conditions. 20 cm observations will be attained for 2 Pallas and 4 Vesta. If the new cooled 3.3 mm receiver is available for the 12 m Kitt Peak antenna, we will attempt observations of 15 Eunomia and 704 Interamnia. The results for 2 Pallas, 4 Vesta and 10 Hygeia will be submitted for publication. The review chapter will be published and the results on Asteroid photometeric diameters will be published.

d. Summary Bibliography:

Webster, W.J., Jr., Hobbs, R.W. and Lowman, P.D., Jr. (1984), Detection of =2 cm Emission from Minor Planet 15 Eunomia, Icarus, 60, 538.

Webster, W.J., Jr., Hobbs, R.W. and Lowman, P.D., Jr. (1987), Detection of = 2 cm Emission from Minor Planet 704 Interamnia, Icarus, 69, 29.

Webster, W.J., Jr. (1987, On the Simple Models for the Interpretation of Centimeter-Wavelength Radio Observations of Asteroids, PASP, 99, 1009.

Webster, W.J., Jr., Johnston, K.J., Hobbs, R.W., Wade, C.M., Lowman, P.D., Jr., and Seidlelman, P.K. (1988), The microwave spectrum of Asteroid 1 Ceres, Astronomical Journal, 95, 1263.

N89-16695

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

ASTROMETRIC OBSERVATIONS OF ASTEROIDS AND SMALL BODIES

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109-8099

INVESTIGATOR'S NAME

James G. Williams

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a) Strategy: Comets and asteroids are observed with the Palomar 1.5m telescope using a CCD array. The goal is observations of astrometric quality (the reduction to positions is separately funded) and the priorities are comets plus minor planets which are planet crossers, Trojans, Hildas, have high inclinations, or otherwise have unusual orbits. The stress is on recoveries of comets and asteroids seen at previous oppositions and follow up on newly discovered objects. Surveys and new discoveries are not being attempted. The modest amount of available dark time is used for faint objects, while brighter objects can be followed in the more plentiful light time. Since asteroids are usually discovered near perihelion when bright, the next several opportunities for recovery are normally fainter. Thus recoveries and follow up with big telescopes complement surveys by smaller instruments.

b) Accomplishments: During the past year two periodic comets were recovered. They were P/Jackson-Neujmin (1987t) and P/Longmore (1987c1). Both were shared recoveries. A follow up observation of the newly-discovered comet Rudenko (1987u) appeared on an IAU card as did the newly discovered comet Maury-Phinney (1988c). A magnitude 14.4 outburst of comet Schwassmann-Wachmann 1 was recorded at the end of May and was reported on an IAU card. Follow up observations of the newly-discovered Amor asteroid 1987 QB were also reported on the cards. A variety of additional comets and interesting asteroids, including more than a dozen planet crossers, were also recorded. The planet crossers 3752=1985 PA, 3753=1986 TO, and 3838=1986 WA were recovered and the Amor asteroid 1987 SL was tracked for six months.

c) Proposed Research: The CCD observing program will be continued on the 1.5m Palomar telescope for the recovery of faint comets and minor planets. The priorities will emphasize first opposition follow up and second opposition recovery. This is not a survey program. Comets and unusual asteroids will be given priority.

d) Publications

The comet recoveries and other time-critical observations were presented on International Astronomical Union Cards 4438, 4443, 4451, 4455, 4493, 4562, and 4606.

N89-16696

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Physical Studies of Small Asteroids and Cometary Cores

PERFORMING ORGANIZATION

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

INVESTIGATOR'S NAME

Wieslaw Z. Wisniewski

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. Strategy: The main goal of our research is to carry on extensive study of physical properties (colors and variability) of asteroids in the 1-10 km diameter range and of cometary cores, with the use of CCD camera, PMT photometer, or both. Particular attention is paid to asteroids being observed by radar because the greatest gain is found from the combination of radar results with the data obtained by optical techniques.

b. Accomplishments: To satisfy our goal 100 nights/year have been scheduled on the 2.3m and 1.5m telescopes. During the past 2 years 42 small asteroids were observed. Out of 22 asteroids for which periods of rotation could be precisely measured, 17 have periods of rotation less than 5 hours. This indicates that small objects rotate faster indeed. By now we know 14 asteroids with rotation periods in the 2 hours range. At the same time we confirm, the existence of a number of exceptionally slow rotators e.g. 1367 Nongoma with P=5.65 days. Our taxonomic observations lead to a conclusion that Apollo, Amor, and Aten asteroids represent a variety of classes and are not predominantly of class S. Apollo asteroid 3361 Orpheus was found to belong to the rare class V. In collaboration with Dr A. Harris of JPL the opposition effect was studied for 30 Urania and 64 Angelina. Seven comets: P/Helin, P/Brooks 2, P/Klemola, P/Borrelly, Wilson (1986 1) and Shoemaker (1987 o) were monitored for variability. The results were negative with the exception of P/Brooks 2 for which 0.35 mag amplitude was detected.

c. Anticipated Accomplishments: The analysis of the data and comparison with the data already published should lead to better understanding of rotation rates of asteroids and their taxonomic classes as a function of size, type and possibly location.

d. Publications

Wisniewski, W.Z., and McMillan, R.S.: Differential CCD Photometry of faint asteroids in crowded star fields and non-photometric sky conditions. Astron. J., 93, 1264, 1987.

Wisniewski, W.Z.: Photometry of Six radar Target Asteroids. Icarus 70, 566, 1987.

Goebel, J.H., Moss, N., Cohen, M., McCreight, C.R., Witteborn, F.C., Rank, D. and Wisniewski, W.Z.: Narrow Band Imagery in the 8-14 Micron Spectral Region. Proc. SPIE. 686, 114, 1987.

Wisniewski, W.Z.: Optical Ground Support for Space, Radio and Large Optical Telescopes. Proc of the Strasbourg Colloquium on " The Coordination of Astronomical Projects". Ed. C. Sterken. Cambridge Univ. Press. (in Press).

N89-16697

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Chemical Abundances of Comets

PERFORMING ORGANIZATION

Department of Physics and Astronomy
Arizona State University
Tempe, AZ 85287

INVESTIGATOR'S NAME

Susan Wyckoff
Peter Wehinger

DESCRIPTION (a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)

Strategy - Observations of NH_2, [OI] and molecular ion spectra in comets represent virtually all of the volatile fraction of a comet nucleus. Their study leads to the N_2, NH_3, H_2O, CO_2, CO content of the nucleus, and thus to important constraints on models of comet formation and chemical processing in the primitive solar nebula. The observations of comet Halley provide the opportunity for the first comprehensive determination of the abundances in a comet nucleus.

Accomplishments - The carbon isotope abundance ratio, $^{12}C/^{13}C = 65 \pm 8$ has been determined for comet Halley from resolved rotational line structure in the CN B-X (0,0) band. This ratio is $\sim 30\%$ lower than the solar system value, 89, indicating either an enhancement of ^{13}CN or a depletion of ^{12}CN in the comet. Scenarios consistent with the observed carbon isotope ratio are: 1) formation of the comet at the periphery of the solar nebula in a fractionation-enriched ^{13}CN region, or hidden from ^{12}CN enrichment sources, and 2) capture of an interstellar comet.

Long-slit CCD spectra obtained at the time of the spacecraft encounter of comet Halley have also been analyzed. Scale lengths, production rates and column densities of CH, CN, C_2 and NH_2 were determined. We find that NH_2 can be modeled well with a two-step decay point-source model, and that the ammonia abundance, $NH_3/H_2O \sim 0.003$, $\sim$ ten times smaller than determined from the GIOTTO ion mass spectrometer. The carbon-bearing species could not be fitted with the point-source model which indicates that a significant fraction of these radicals arise from a distributed source such as the CHON particles.

Moderately strong, unidentified molecular ion bands were discovered in the plasma tail spectra of comet Halley. No known laboratory molecular ion spectrum can account for the new cometary bands.

Analysis of pre- and post-perihelion spectra of comet Giacobini-Zinner using a Monte Carlo model confirm the low C_2/H_2O ratio, and indicate a very low NH_3/H_2O ratio.

In Progress - Fluorescence efficiencies and column densities of ions observed in the plasma tail of comet Halley are being determined. The observed ions, CO_2^+, CO^+, CH^+, OH^+, H_2O^+ and N_2^+, derive from the most abundant molecular species in the nucleus. Hence their relative abundances will provide important constraints on the nucleus abundances, the coma chemistry, and ultimately on the chemical processing in the primitive solar nebula.

The N_2/NH_3 abundance ratio in comet nuclei is diagnostic of the physical conditions where comets form in the solar nebula. This abundance ratio will be determined for comet Halley, and other comets in which N_2^+ and NH_2 features are observed.

A dust production model is being developed to determine dust production rates from optical continuum spectra in comets. Pre- and post-perihelion observations of comet Halley will be analyzed for gas and dust production rates as a function of heliocentric distance to determine relative abundances and to test for inhomogeneities in the nucleus.

PUBLICATIONS

Spectra of the Plasma Tail of Comet P/Giacobini-Zinner, S. Wyckoff, P. Wehinger, S. Konno, H. Spinrad and M. J. S. Belton, *20th ESLAB Symposium on the Exploration of Halley's Comet*, **ESA SP-250 I**, 499, (1986).

A Precise Spin Period for P/Halley, M. J. S. Belton, P. A. Wehinger, S. Wyckoff, H. Spinrad, *20th ESLAB Symposium on the Exploration of Halley's Comet*, **SP-250 I**, 599, 1986.

New Molecular Ions in Spectra of Comet P/Halley, S. Wyckoff, P. A. Wehinger, H. Spinrad, and M. J. S. Belton, *20th ESLAB Symposium on the Exploration of Halley's Comet*, **SP-250 III**, 311, 1986.

The Violet CN (0-0) Band R-Branch Spectrum of Comet Halley, P. A. Wehinger, B. A. Peterson, S. Wyckoff, E. Lindholm, and M. Festou, *20th ESLAB Symposium on the Exploration of Halley's Comet*, **SP-250 III**, 473, 1986.

The Swan C_2 (0-0) Band in Comet Halley, P. A. Wehinger, B. A. Peterson, S. Wyckoff, E. Lindholm, R. Gredel, E. van Dishoeck, and J. H. Black, *20th ESLAB Symposium on the Exploration of Halley's Comet*, **SP-250 III**, 475, 1986.

Ground-Based Constraints on the H_2O^+/CO^+ Abundance Ratio and Dust Impact Rate in in Comet Giacobini-Zinner, R. M. Wagner, B. L. Lutz, and S. Wyckoff. *Astrophys. J.*, **322**, 544, (1987).

Spectra of Comets P/Grigg-Skjellerup (1986m) and P/Halley, P. A. Wehinger and M. J. S. Belton, *IAU Circ.*, No. 4311, 1987.

The Spectral Behavior of P/Halley at Large Heliocentric Distances in Light of the Giotto/Vega Results, M. J. S. Belton, H. Spinrad, P. A. Wehinger, S. Wyckoff, and D. K. Yeomans, *Astron. Astrophys.*, **187**, 569, 1987.

Abundances in Comet Halley at the Time of the Spacecraft Encounters, S. Wyckoff, S. Tegler, P. A. Wehinger, H. Spinrad, and M. J. S. Belton, *Astrophys. J.*, **325**, 927, 1988.

The Carbon Isotopes in Comet P/Halley, S. Wyckoff, E. Lindholm, P. A. Wehinger, B. A. Peterson, J.-M. Zucconi, and M. C. Festou, *Astrophys. J.*, (in press), 1988.

Excitation of CO_2^+ in Comets, S. Wyckoff and S. Leach, *Astrophys. J. Letters*, (in press), 1988.

Identification of CO_2^+ Features in the Plasma Tail Spectrum of Comet Halley, S. Wyckoff and S. Leach, *Astrophys. J. Letters*, (in press), 1988.

Pre- and Post-Perihelion Dust and Gas Production Rates in Comet Halley, S. Wyckoff, and P. Wehinger, (in preparation), 1988.

On the Ammonia Abundance in Comet Halley, S. Wyckoff, S. Tegler, and S. Konno *Astrophys. J. Letters*, (in preparation), 1988.

N89-16698

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
RESEARCH AND TECHNOLOGY RESUME

TITLE

Comet and Asteroid Dynamics

PERFORMING ORGANIZATION

Jet Propulsion Laboratory
Pasadena, CA 91109

INVESTIGATOR'S NAME

Donald K. Yeomans

DESCRIPTION *(a. Brief statement on strategy of investigation; b. Progress and accomplishments of prior year; c. What will be accomplished this year, as well as how and why; and d. Summary bibliography)*

a. **Strategy**: In order to provide observers with accurate ephemerides of comets and asteroids, up-to-date astrometric positions must be used to improve the existing orbits. For active comets, nongravitational forces must be taken into account; these forces are assumed due to the rocket-like effect of outgassing cometary ices and are used to characterize the volatility and rotation properties of icy cometary nuclei. In an effort to improve ephemeris accuracies, the benefits of a new nongravitational force model for comets as well as new radar data types are being investigated.

b. **Accomplishments**: The first successful attempts to improve the orbits of close Earth approaching asteroids using radar data have been completed for asteroids 1982XB and 1986JK. The radar Doppler measurements of 1982XB, made on Dec. 5-6, 1987, were represented to less than 0.1 Hz while the Doppler observations of 1986JK, made on May 28 - June 1, 1986, were represented to within a few Hz for each of the 11 measurements. Last minute orbit updates for asteroid 324 Bamberga allowed a successful stellar occultation prediction to be made on Dec. 8, 1987. A new paradigm for the cometary nongravitational force model has been successfully tested on a few comets. This new model allows the water vaporization curve to peak on either side of perihelion, thus introducing a nongravitational force via an asymmetric radial force, rather than through a symmetric transverse effect that the old model requires. Preliminary results suggest that the optimum locations of the water vaporization peak, required for the nongravitational forces, aligns with the locations of the visual light curve peaks.

c. **Anticipated Accomplishments**: The new orbit determination techniques will be used to compute additional "radar" orbits for close Earth approaching asteroids. The new nongravitational force model paradigm will be applied to additional comets whose light curves are asymmetric with respect to perihelion.

d. **Publications**

Belton, M.J.S., Spinrad, H., Wehinger, P.A., Wyckoff, S., and Yeomans, D.K.: The Spectral Behavior of P/Halley at Large Heliocentric Distances in Light of the Giotto/Vega Results. Astronomy and Astrophysics, 187, 569, 1987.

Yeomans, D.K., Ostro, S.J., and Chodas, P.W.: Radar Astrometry of Near-Earth Asteroids. Astronomical Journal 94, 189, 1987.

Yeomans, D.K. and Keesey, M.S.: Orbit for Minor Planet 1981 Midas. Minor Planet Circular 12194, dated Sept. 7, 1987.

Yeomans, D.K.: Orbits for Asteroids 243 Ida, 951 Gaspra and 2825 (1938 SD1). Minor Planet Circular 12687, dated Jan. 4, 1988.

H I G H L I G H T S

O F

R E C E N T A C C O M P L I S H M E N T S

I N

P L A N E T A R Y A S T R O N O M Y

ASTEROID 324 BAMBERGA ACCURATELY SURVEYED WITH GROUND-BASED TELESCOPES. . . . . W. B. HUBBARD, R.L. MILLIS

In the course of a computerized comparison of asteroid ephemerides with the positions of stars listed in star catalogs, we discovered a couple of years ago that 324 Bamberga would occult the 10th magnitude star, AG+40°0783 on December 8, 1987. The precise region of the Earth from which this occultation would be visible was initially somewhat uncertain, but plates taken at Lick Observatory and Lowell Observatory in November and early December 1987 gave a groundtrack stretching from China, across Japan, and on through the southwestern United States. Lowell Observatory and the University of Arizona's Lunar and Planetary Laboratory jointly fielded six teams equipped with specially designed portable occultation observing systems. Permanent observatories and amateur astronomers along the path were also alerted. As a result of these efforts, the occultation was successfully observed at 13 sites, including three of those manned by Lowell and University of Arizona astronomers. The event was also recorded in China and Japan. The observations resulting from this worldwide cooperative effort have shown that Bamberga is about 10% smaller than previously believed and have revealed large irregularities along the small planet's limb. Analysis of the data is continuing.

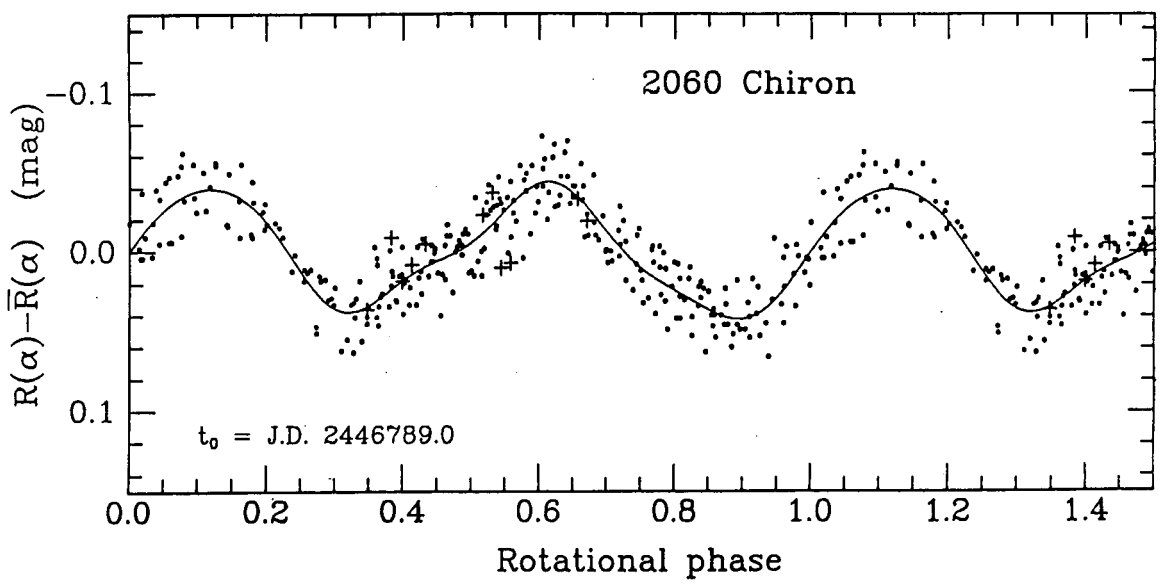
RADAR ECHOES FROM ASTEROID 1986 DA INDICATE A METALLIC COMPOSITION . . . . . S. J. OSTRO

Dual-polarization, 13-centimeter-wavelength radar observations of this near-Earth asteroid were carried out at the Arecibo Observatory in April 1986, two months after its discovery. Resolution of the echoes in Doppler frequency (radial velocity) and, on one date, in time delay (distance) show this object to be 1 to 2 km in size and to have an extremely irregular, nonconvex, and possibly bifurcated shape. However, the echo polarization shows the asteroid's surface to be very smooth at centimeter-to-meter scales. The measured radar cross section, when combined with all available constraints on the object's dimensions, yield a radar reflectivity more than twice as large as that estimated for any of the several dozen other radar-detected asteroids and about ten times the lunar value. The most plausible interpretation of this radar signature is that 1986 DA's composition is very rich in metal, and that there is little coverage of the surface by regolith thicker than a few cm.

The radar results strongly favor the hypothesis that 1986 DA is a metallic fragment, perhaps the core of a small mainbelt asteroid that melted, differentiated, and cooled about 4.5 billion years ago, and then was disrupted in a catastrophic collision. This object might be, or share, the source of some of our iron meteorites -- analysis of samples from the asteroid's surface might reveal which of those two alternatives is more likely, and would elucidate mechanisms responsible for delivering material into the inner solar system.

2060 Chiron is the most distant object classified as an asteroid. Its unique Saturn- and Uranus-crossing orbit is subject to strong perturbation by Saturn on a timescale of thousands of years; as a consequence, Chiron cannot be regarded as a member of a putative stable cloud of asteroidal objects between Saturn and Uranus. Indeed, Chiron's orbit is chaotic and appears to be evolving inward, perhaps like the orbits of the short-period comets. Hence, there is strong expectation that Chiron originated either in the outer solar system or in the Oort Cloud.

From R-band CCD photometry of 2060 Chiron carried out on nine nights in November and December 1986 and on 23 March 1988 (see figure on next page), we found the synodic rotation period to be 5.9180 $\pm$ 0.0001 hr and the peak-to-peak lightcurve amplitude to be 0.088 $\pm$ 0.003 mag. From the 1986 data, the absolute magnitude is $H_R = 6.24 \pm 0.02$ mag and the slope parameter is $G_R = 0.70 \pm 0.15$, though formal errors may not be realistic. The lightcurve has two pairs of extrema, but its asymmetry, as evidenced by the presence of significant odd Fourier harmonics, suggests macroscopic surface irregularities and/or the presence of some large-scale albedo variegation. The 1986 observations show no evidence of periodic or nonperiodic brightness changes that can be ascribed to comet-like activity. In contrast, the 1988 observations indicate a brightening of Chiron by 0.6 $\pm$ 0.1 mag, which confirms the finding by Tholen *et al.* (1988, *IAU Circ.* 4554) and is consistent with our 1978 electronographic photometry. The lightcurve amplitude appears to be unchanged, however, and image profiles are indistinguishable from those of stars in both 1986 and 1988. Chiron may recently have been varying nonasteroidally on timescales greater than a month or two; but it is also possible that the asteroid's intrinsic brightness has been bistable over the past decade, with an excursion of 0.58 $\pm$ 0.14 mag on a timescale of some years.



Shortly after its discovery in 1977 by C. T. Kowal, asteroid 2060 Chiron was suspected to exhibit anomalous changes in brightness unlike normal asteroids. Chiron has a mean solar distance between Saturn and Uranus, but it crosses within Saturn's orbit (perihelion 8.5 AU). In February 1988, W. K. Hartmann, D. J. Tholen, and D. P. Cruikshank observed Chiron photometrically (VJHK) at the NASA Infrared Telescope Facility on Mauna Kea and found the object to be 0.7 mag brighter than the "ephemeris" magnitude established by Tholen over several years of photometric observations. The anomalous brightening was quickly confirmed in data taken subsequently with the 2.24-m Univ. of Hawaii telescope and at Lowell Observatory, and also in data taken about two months earlier with the 2.24-m Hawaii telescope (by K. Meech and D. Jewitt). At the time of the apparent outburst of Chiron, it was at a solar distance of 12 AU. Chiron appears to have retained a substantial volatile component that has a significant vapor pressure at very low temperature, suggesting that it is not water ice. Additional observations are planned in order to characterize the nature of the activity more completely and to search for extended emission from the object.

THE FIRST IMAGES OF THE SURFACE OF AN ASTEROID. . . J.D. DRUMMOND

The first glimpses of an asteroid's surface have been obtained from images of 4 Vesta reconstructed from speckle interferometry data. These images reveal dark and bright patterns, reminiscent of our Moon. Dark areas so dominate one face of Vesta that a minimum in the lightcurve occurs when the maximum cross-sectional area is visible, leading to lightcurves with one maximum and one minimum per rotation, instead of the usual two of each. The derived shape for Vesta is not consistent with the notion of its having been differentiated to the point of adopting a hydrostatic equilibrium figure. However, the images are consistent with differentiation since the dark areas may be interpreted as 'lava flows'. In fact, the non-equilibrium shape may be an indication of a large 30km high volcano near Vesta's equator that produces an equatorial bulge.

ORGANIC MATTER ON ASTEROID 130 ELEKTRA . . . . . D.P. CRUIKSHANK

D. P. Cruikshank and R. H. Brown reported evidence for the presence of a spectral absorption band indicative of organic material on the surface of asteroid 130 Elektra. Telescopic observations made with the NASA IRTF and the Cooled Grating Spectrometer showed absorptions at 3.4 micrometers that agree well with a similar band found in laboratory spectra of certain carbonaceous chondrite meteorites. In the meteorites, such as Murchison, Murray, and Orgueil, the band indicates organic matter, or macromolecular carbon, of nonbiological origin. The asteroid observed by Cruikshank and Brown is a G-type body, meaning that it has a very low albedo and contains water of hydration in the surface materials. Asteroids of this type have long been though to be potential parent bodies of the primitive carbonaceous chondrites, and may also be related to the very low albedo material found on certain planetary satellites and on the surfaces of some cometary nuclei. Both the albedo and the bound water are consistent with the carbonaceous chondrites noted above. This discovery is being pursued in collaboration with J. R. Piscitelli (Ph.D. student, Univ. of Hawaii) through observations of other candidate asteroids, some of which have already shown similar bands to that found in 130 Elektra.

PHOTOMETRY OF HIRAYAMA FAMILY ASTEROIDS . . . . . R. P. BINZEL

Once every 124 years, nature provides earth-bound astronomers with the opportunity to observe occultation and transit phenomena between Pluto and its satellite, Charon. Ground-based observations of these events allow precise physical parameters for the Pluto-Charon system to be derived which are unlikely to be improved upon until *in situ* spacecraft observations are obtained. This program supports photometry observations from McDonald Observatory, a critical location in an International Pluto Campaign network. Knowledge of the diameters, masses, densities, and compositions derived from these observations will augment our understanding of Pluto's origin and its context within the problem of solar system formation. Reduction and analysis of 1987 multi-color photometry has provided individual colors for Pluto and Charon and has shown they have relatively uniform hemispherical distributions (Binzel 1988a). During 1988, observations of 8 additional mutual events have been obtained or attempted.

A second task supports research on the evolutionary processes which have occurred in the asteroid belt by measuring the physical properties of specific Hirayama family members. Photoelectric lightcurve observations of Koronis and Themis family members are used to investigate the individual catastrophic collision events which formed each family. By comparing these properties with results of laboratory and numerical experiments, the outcomes of catastrophic disruptions and collisional evolution may be more precisely determined. New lightcurve observations have been obtained for ~20 asteroids in the Koronis and Themis families and also targets of opportunity such as the Galileo flyby target 243 Ida. A preliminary analysis supports the hypothesis (Binzel 1988b) of a recent formation for the Koronis family.

ASTROMETRIC OBSERVATIONS OF ASTEROIDS AND SMALL BODIES

J.G. WILLIAMS

The recovery of returning periodic comets and planet crossing asteroids is a major goal of this observational program. The Palomar 1.5 m telescope equipped with a CCD is used to hunt for the targets early in an apparition when they are still faint. During the past year there have been shared recoveries of periodic comets Jackson-Neujmin and Longmore. Recoveries were also made on the earth crossing asteroids 1985 PA, 1986 TO, and 1986 WA. All three of these have subsequently been numbered: 3752, 3753, and 3838, respectively. Recoveries are not the only goal. In all more than a dozen comets and more than a dozen planet crossing asteroids were tracked so that accurate orbits could be derived. There are occasional surprises; periodic comet Schwassmann-Wachmann 1 is normally faint, but at the end of May a magnitude 14.4 (r) outburst was recorded.

CCD SCANNING FOR COMETS AND ASTEROIDS . . . . . T. GEHRELS

A new technique of scanning with a charged-coupled device (CCD) has been developed at the University of Arizona and it is being tested on asteroids and comets with the "Spacewatch Telescope," which is the 91-cm Newtonian reflector of the Steward Observatory on Kitt Peak.

A 2048 x 2048 CCD is being installed, and that will make the Spacewatch Telescope a rare facility having CCD-scanning to a visual limiting magnitude of about 21.5, at the 6-sigma detection level, with the largest CCD detector in the world.

THE PALOMAR PLANET-CROSSING ASTEROID SURVEY (PCAS) . .E. F. HELIN

Results from 13 observing run at Palomar have produced 225 new asteroids which includes Apollo asteroid, 1988 EG, the only near-Earth asteroid discovered in 1988 (June, 1988), Amor 1987 QB, 12 Mars-crossers, several inner-belt, high inclination asteroids, which do not fall into any well-defined regions, and 6 Hungarias and 13 Phocaeas. Our observations from the 1.2*m* Oschin Schmidt represent the recovery positions of the long lost asteroid (1026) Ingrid. Two new unusual short-period comets have been discovered; P/Singer-Brewster, 1986d, and P/Helin, 1988w. P/Singer-Brewster is in a 2:1 resonance with Jupiter while P/Helin with an aphelion near Saturn, is tugged between Jupiter and Saturn during its 21-year period around the sun. INAS collaboration continues successfully. Apollo discovery 1987 SB is a find of our Bulgarian colleagues with nearly simultaneous confirming observations by PCAS at Palomar. Five PCAS near-Earth asteroids have been recovered and numbered recently.

COMET AND ASTEROID DYNAMICS . . . . . D. K. YEOMANS

Recent enhancements, in traditional orbit determination techniques for asteroids and comets, have been used to greatly improve the accuracy of existing orbits and ephemerides for these objects; radar Doppler and range data can now be used, along with optical astrometry, to rapidly update their orbits and ephemerides. An extensive error analysis has shown that the use of radar data offers dramatic improvements in future ephemeris accuracies for close Earth approaching asteroids. Rapid updates to existing orbits allowed successful radar Doppler observations of asteroid 1982 XB (in December 1987) and of asteroid 1986 JK (in May - June 1986), and the resultant Doppler measurements have been used to further update their orbits and improve the chances of recovery at their future close Earth approaches in November 1992 and July 2000 respectively. A new paradigm for the cometary nongravitational force model has been successfully tested on a few comets. This new model allows the water vaporization curve to peak on either side of perihelion, thus introducing a nongravitational force via an asymmetric radial force, rather than through a symmetric transverse effect that the old model requires. Preliminary results suggest that the optimum locations of the water vaporization peak, required for the nongravitational forces, aligns with the locations of the visual light curve peaks. This new paradigm should allow an improved understanding of long term cometary rotation properties.

STUDY OF COMETS . . . . . M. F. A'HEARN

The apparition of Comet Wilson in 1987 provided a dramatic opportunity to compare a dynamically new comet with a highly evolved one since Wilson and Halley were comparably bright and comparably active. Although no chemical differences have yet been reported, the photometric and morphological behavior of the two comets was dramatically different. P/Halley showed factors of 2 variations in outgassing from day to day as well as dramatic jets - both dusty ones and ones composed only of radicals as far as we could observe. Wilson on the other hand showed none of these phenomena. The brightness remained nearly constant from day to day and the coma was almost totally amorphous as seen both in the continuum and the emission bands of neutral radicals. This difference is qualitatively consistent with the development of an inert mantle on P/Halley with only small active areas that have broken through the crust. Wilson has not yet had the opportunity to develop an inert mantle.

IMAGING OF SPECTROSCOPY OF COMET P/HALLEY . . . . . M. R. COMBI

The goals of this investigation are the analysis of a large set of high-resolution echelle/reticon spectra, and the reduction and analysis of a set of IAU narrow-band-filtered CCD images of comet Halley taken during the pre-perihelion period at Oak Ridge Observatory (CFA/SAO) by Dr. R. E. McCrosky. The scientific objectives associated with these goals are the determination of the spatial distributions of several important radicals, atoms and ions in the coma. These include C_2, CN, C_3, H_2O^+ and CO^+ from the image data and the $O(^1D)$ to NH_2 ratio from the spectral data. The analysis of the neutral species distributions with our Monte Carlo models, will aid in the understanding of their production and decay mechanisms as well as serve as an important indicator of the physical conditions in the inner coma. The spatial distributions of the ions will serve as a guide to constrain the complex models necessary for understanding the interaction of the solar wind and the cometary ions. During this past year we have completed the reduction of the standard star photometry and the re-flat-fielding of a number of the comet images. During the upcoming final year of this work we plan to complete the absolute calibration of the CCD images for inclusion in the IHW archive, to analyze a select portion of the neutral radical images with our Monte Carlo models, and to present the results of the 6300Å region spectra which will serve as a guide for low resolution observers in order to yield the unambiguous separation fo the contributions of cometary $O(^1D)$, airglow $O(^1D)$, and the numerous NH_2 lines in that region of the spectrum.

COMET BOWELL AT RECORD HELIOCENTRIC DISTANCE . . . . D. C. JEWITT

Much evidence exists to show that activity in comets is driven primarily by the sublimation of water ice. Thermal equilibrium calculations show that water ice nuclei are too cold to sublimate substantially at heliocentric distances R > 6 AU (after all, the water ice satellites of Jupiter do not sublimate at R ≈ 5 AU!). Thus, comets at R > 6 AU should be inert, and ought to appear devoid of coma. Observations of P/Halley on the inbound leg of its orbit were in general agreement with this picture; the comet was an inactive nucleus until R ≈ 6 AU, at which point a coma of gas and dust progressively developed.

In contrast, we have discovered an extensive coma in a comet at the much larger heliocentric distance R = 13.6 AU (Meech and Jewitt (1987), Nature, **328**, 506). This is the largest distance at which a comet has been observed, and the largest distance at which direct evidence for activity has been obtained. The observations were taken with a charge coupled device (CCD) at the 2.1m telescope of Kitt Peak National Observatory. The detection was difficult because of the low surface brightness of the coma - only a fraction of a percent of the surface brightness of the night sky. Total integrations of 1 hour were needed to detect the comet, which was conclusively identified from its motion with respect to field stars in the expected direction at the expected rate.

Comet Bowell at R = 13.6 AU shows a coma 30" (2×10^8 m) in diameter and presents a cross section of about 100 km^2. Comparison with previous photometric observations shows that the coma has been in steady expansion since the time of discovery (1980) with a speed v = 1 m s^{-1}. The rate of mass loss is declining with increasing R, at a rate which is consistent with the sublimation of CO_2 (rather than H_2O) on the surface of its nucleus. Both properties differ from the properties of "typical" comets and both challenge our understanding of cometary physics. Photometric extrapolations suggest that it may be possible to study comets out to the orbit of Neptune (R = 40 AU), with existing CCD technology, thus opening a new realm for the investigation of these ethereal bodies.

COLLAPSE OF COMET HALLEY'S ATMOSPHERE FOLLOWED DURING 1988

M.J.S. BELTON

During the first three months of 1988 the total brightness of Comet Halley was observed to drop rapidly (by a factor of approximately 50) as it moved away from the sun to beyond 8 AU. This rapid decrease is the first clear signal that activity on the nucleus is finally terminating. The comparison of the heliocentric distances at which the nucleus activity "turned on" (5 AU) and "turned off" (8 AU) should help put significant constraints on the nature of the volatiles responsible for the activity and the efficiency with which heat is transported in the surface layers of the nucleus. The observations were made at the University of Hawaii's 88" telescope on Mauna Kea by E. Alvarez, K. Meech, and M. J. S. Belton.

CHEMICAL ABUNDANCES IN COMETS . . . . . S. WYCKOFF

An accurate determination of the carbon isotope ratio has been determined for the first time in a comet. Spectra of the CN B-X (0,0) band in comet Halley resolve the ^{13}CN rotational line structure and indicate an essentially model-independent abundance ratio, $^{12}C/^{13}C = 65 \pm 8$. The comet ratio is $\sim$ 30% lower than the solar system value, 89, and indicates a formation site for the comet different from the Uranus-Neptune region. We conclude 1) that either the comet formed at the periphery of the solar nebula, perhaps in the inner Oort Cloud, or 2) that comet Halley is a captured interstellar comet.

The ammonia abundance in comet Halley has been determined from NH_2 bands in optical spectra. The abundance ratio $NH_3/H_2O \sim 0.003$ indicates a low ammonia abundance in the nucleus, and is $\sim$ ten times smaller than the ammonia abundance inferred from the GIOTTO ion mass spectrometer results.

THE APPLICATION OF P/HALLEY RESULTS TO PREVIOUS COMETARY SPECTROPHOTOMETRY . . . . . H. SPINRAD

With R.L. Newburn of JPL, I have been applying several changed physical assumptions on the cometary nucleus and dust size distribution to our existing quantitative spectrophotometry. Many comets, perhaps all of them, have nuclei that are larger and darker than previously assumed. The nucleus itself does make a significant contribution to the continuum light of the inner coma, and its gravitational deceleration on the escaping dust is no longer negligible. These two factors and the new size-distribution of dust grains slightly modify the dust production rates calculated by NSII (1985).

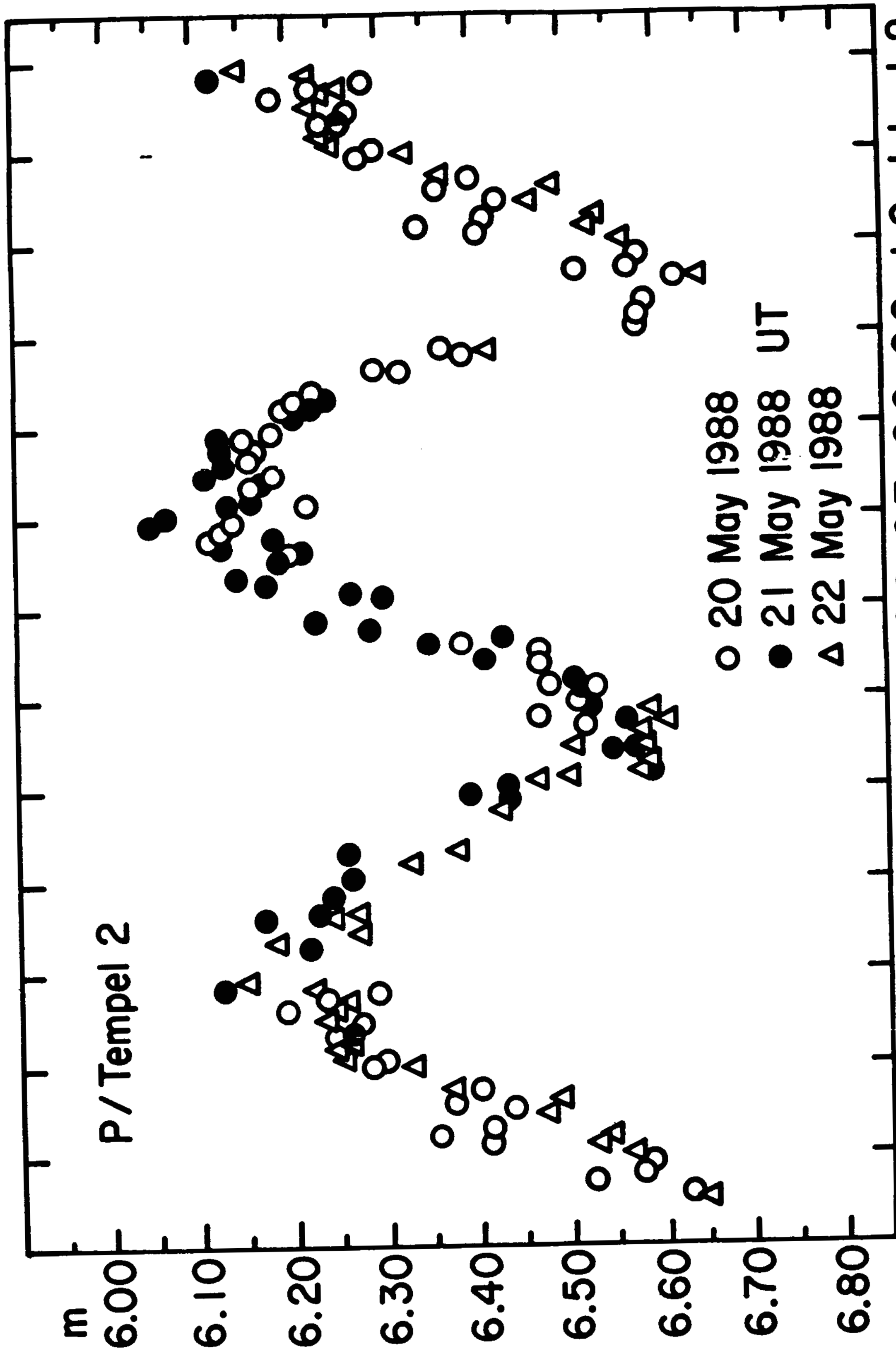
The gas production rates for the comets have also been improved: the CN emission rate factors were updated from Tatum (1984) and more important, a full Haser-model formulation for Q(OI) has replaced the approximation suggested by Spinrad (1982). The conversion of oxygen to total water production rates now includes an actual measure of the solar Lyα flux to explicitly assess the water photo-dissociation by line radiation. The dominant water production rates derived for P/Halley seem quite secure.

RESOLUTION OF A PROBLEM IN THE PRODUCTION RATE OF THE OH RADICAL IN COMETARY COMAE . . . . . W. M. IRVINE

For a number of years there has been a discrepancy between the production rate calculated for the OH radical in cometary comae as derived from ultraviolet compared to that from radio observations. The ultraviolet-derived production rates are generally observed to exceed those obtained from radio data by a factor of a few. Several investigators have speculated that the difference might be related to collisional quenching of the $^2\Pi_{3/2}$ J=3/2 Λ-doublet that is inverted by solar ultraviolet radiation and is responsible for the 18cm radio emission. Although such work has established that collisions can profoundly affect the radio emission, this effect has not been generally accepted as the explanation of the ultraviolet-radio discrepancy, partly because serious model-dependent differences often exist between analyses of the observations of the two wavelengths. Moreover, no quantitative model of the distribution of OH radio emission in the coma when quenching is present has heretofore been presented. Schloerb has now carried out a detailed model of the process, including collisions with ions in the coma using data obtained from the spacecraft encounters with Comet Halley, and has concluded that collisional quenching is indeed the most likely explanation for the discrepant production rates previously reported. This effect may provide a means in the future to probe the ion and electron content of cometary comae via OH radio observations.

INFRARED IMAGING OF COMETS . . . . . C. M. TELESCO

We are studying the dust properties of comets by imaging at 8-30 μm using a very sensitive 20 pixel bolometer spatial array developed at NASA - MSFC. We have obtained unique infrared images of Comets Giacobini-Zinner, Halley, and Wilson, as well as unresolved first detections of both Wilson and Tempel 2. By combining these images with visual observations and with dynamical analyses of the dust, we have been able to determine detailed properties of the dust particles including sizes, ejection velocities, mass loss rates, and albedos (we have constructed the first albedo map of a comet, Giacobini-Zinner). For example, we have shown that Comet Giacobini-Zinner contains a component of large grains (sizes $\sim$ 300 μm) which are evident as a distinct inner dust tail. Our images of Halley in March 1987 reveal clear night-for-night brightness variations attributable to nuclear rotation. We have also taken advantage of the excellent performance of our array to do some non-cometary research relevant to the exploration of our solar system: we have made the first spatially resolution detection from the ground at 10 and 20 μm of the protoplanetary disk around the star β Pictoris. These observations tightly constrain the disk geometry.



P/Tempel 2 lightcurve obtained with the standard photoelectric photometer on 1.5 meter telescope. 17 arcseconds diaphragme. Visual magnitude at maximum is 15.51 mag. Derived synodic period is 8^h58^m.

HEAVY WATER DETECTED IN THE MARTIAN ATMOSPHERE: FIRST ESTIMATE OF THE D/H RATIO ON MARS. . . . . B. LUTZ, T. OWEN

Using the high-resolution Fourier Transform Spectrometer on the Canada–France–Hawaii 3.6-meter telescope on Mauna Kea, Tobias Owen (State University of New York at Stony Brook) and Barry L. Lutz (Lowell Observatory), in collaboration with Catherine de Bergh and Jean-Pierre Maillard (Observatoire de Paris—Meudon), detected the spectral signature of heavy water (HDO) in the infrared spectrum of Mars. This signature, comprised of a fundamental rotation-vibration absorption band near 3.7 μm, represents the first detection of deuterium or of any of it compounds on Mars. A quantitative analysis of the absorptions using synthetic spectral techniques, along with a similar analysis of the spectrum of Martian normal water (H_2O) contemporaneously recorded with the same equipment, provides the first measurement of the D/H ratio on the planet. The ratio, determined to be $9 \pm 4.5 \times 10^{-4}$, is a factor 6 ± 3 higher than found on Earth. This enrichment implies a much more rapid escape of hydrogen from Mars in the past, consistent with a denser, warmer primeval Martian atmosphere, than is present today.

RADAR STUDIES IN THE SOLAR SYSTEM . . . . . I. I. SHAPIRO

We continued the ongoing program of radar observations in collaboration with our colleagues S.J. Ostro and M.A. Slade (JPL) and D.B. Campbell (Arecibo and Cornell). Ephemerides were prepared, and observations were carried out at Arecibo, for the numbered asteroids 4, 20, 105, 654, 1566, 1981, 2212, 3554, and 3757. All of these were successfully detected except Icarus (1566), from which we had hoped to improve our determination of the Sun's quadrupole moment and a model parameter for testing general relativity. Post-apparition orbit analyses have shown that, for recently discovered asteroids such as 3757, the inclusion of radar data can be important in predicting the positions at the next apparition. The observing program also included Arecibo observations of Mercury, Venus, and the Galilean satellites of Jupiter. The Mercury observations at Arecibo were all within a week of the epoch of a closure point (same surface position as a previous observation), and one was matched by a near-simultaneous observation at Goldstone.

ADVANCED INFRARED ASTRONOMY . . . . . T. KOSTIUK

Wind velocities at 110 km altitude on Venus were extracted to ~ 1 m/sec from infrared heterodyne measurements of non-thermal emission cores of CO_2 lines near 10.3 μm. Results indicate a subsolar to anti-solar circulation (~ 40 m/sec) with a small retrograde component. Results are being used to constrain existing two dimensional dynamical models.

The study of hydrocarbon abundances and variability on Jupiter is proceeding. Evidence of increased stratospheric temperature with latitude near the north pole was observed from new 12 μm ethane emission line measurements obtained at the IRTF. Ethylene was detected for the first time in the Jovian equatorial region and a mole fraction ~ 4×10^{-10} was retrieved. These results will be used to modify existing models of hydrocarbon photochemistry on Jupiter.

The composition of Comet Wilson (1986e) was investigated from the KAO. Water and methane were detected, and their production rates were measured (H_2O: $3 \cdot 10^{29}$ molecules sec^{-1}; CH_4: $1.2 \cdot 10^{28}$ molecules sec^{-1}). The ortho-para ratio for H_2O was found to be equilibrited at 3:1.

A model for the detection of formaldehyde in comets was developed and initial observations were made on comet Bradfield from the Kitt Peak 4-meter FTS.

RESEARCH AT PALOMAR OBSERVATORY IN PLANETARY ASTRONOMY

B.T. SOIFER

Analysis of seven occulations of the Neptune ring arc system conducted under this program in the last four years, has shown that a minimum of three distinct rings at radii from 54,000 Km - 67,000 Km are required to explain the five highest quality detected events. Such ring arcs are consistent with proposed models of this system. High time resolution, high sensitivity observations of the Uranus rings have continued to provide input data to significantly improve the dynamical model of this system. Near-infrared photometry of a Pluto-Charon eclipse event has shown that these bodies have significantly different surface properties. Three near earth asteroids and two new comets have been discovered as part of the Solar System survey part of this program utilizing the plate material from the new Palomar Sky Survey.

STUDIES OF GERMANE AND ARSINE IN SATURN. . . . . R. F. KNACKE

K. S. Noll, R. F. Knacke, T. T. Geballe, and A. T. Tokunaga reported the detection of the rare gas, germane (GeH_4) in Saturn and possible detection of arsine (AsH_3). Detection of germane shows that Saturn, like Jupiter, has a strongly convective layer in the atmosphere that transports material upward from deep levels. The properties of the deep atmosphere, as well as global abundances, can be probed by observations of trace molecules that are carried up by convective motions.

INTERIORS OF THE GIANT PLANETS . . . . . W.B. HUBBARD

We derived new results on the structure of scintillations in the central flash occultation by Neptune on 20 August 1985 (results related to the mean light curve were published last year). Our analysis shows that scintillations are present throughout the lightcurve, both near the half-intensity points (at a pressure of 1 microbar) and near the central flash (at 0.4 mbar). Near the planetary limb, the scintillations are extended parallel to the limb, but near the shadow center, they are extended in a radial direction. We collaborated with Ramesh Narayan to derive a theory relating the scintillations to density fluctuations in Neptune's atmosphere. The theory will ultimately enable us to test whether the scintillations are caused by internal gravity waves in Neptune's upper atmosphere. We successfully observed the 9 July 1987 Neptune occultation from two stations in the Tucson area, in collaboration with G. and R. Rieke, R. Marcialis, and H. Campins. Further data on Neptune's atmosphere were obtained, but no ring arcs were detected. On 8 December 1987 we successfully observed an occultation by the asteroid Bamberga, in collaboration with a Lowell Observatory group. The resulting data will provide a more accurate determination of the asteroid's size. In collaboration with D. Tholen, we showed that geometrical optics are adequate for interpreting Pluto/Charon mutual events.

CHANGES ON TRITON . . . . . D.P. CRUIKSHANK

The spectrum of Neptune's satellite Triton show absorption bands attributed to methane and to molecular nitrogen. Spectra obtained by D. P. Cruikshank, R. H. Brown, and A. T. Tokunaga in 1987 with the NASA Infrared Telescope Facility at Mauna Kea, confirmed similar data taken one year earlier, and show that the spectrum has changed significantly since 1980. The new spectra, taken with the Cooled Grating Array Spectrometer, show that the methane bands are now weaker than in 1980; the change in strength probably occurred in 1983 or 1984. The change is consistent with the formation of a haze in Triton's atmosphere, but there may be other possible causes as well. In addition, earlier evidence for nonuniform albedo distribution around the surface of the satellite seems to have disappeared, judging from spectra and photometric observations made throughout Triton's 5.88-day orbital cycle. The satellite is in locked synchronous (retrograd) rotation around Neptune, and undergoes extremes in seasonal cycles with a period of about 680 years.

STUDIES OF EXTENDED PLANETARY ATMOSPHERES. . . . . D. M. HUNTEN

The sodium environment of Io has been studied in detail by N. Schneider. Eclipse data were obtained in 1985, and give extremely good height resolution up to nearly 10 Io radii. Densities obtained from these absorption spectra nicely match the densities in the outer regions (to ~100 Io radii) obtained from the intensity scattered in the D lines. The medium so observed resembles a barometric atmosphere at ~1000 K, although it is flowing rapidly outward. The density extrapolates to 8000 per cc at the surface, but there is almost certainly a much larger density of cooler atoms that cannot be observed by this method. It is estimated that the total density (mostly SO_2) is about 100 times greater, and that the exobase lies near or below 1.4 Io radii.

Another data set shows very fast jets of sodium (up to 100 km/sec), frequently tilted out of the orbital plane. The highest speeds are larger than the co-rotation speed of the torus, 70 km/sec, but could be attained by freshly produced ions from the atmosphere before they become thermalized. However, we are observing neutral atoms, not ions. If fresh ions are neutralized (by charge exchange) before they leave the atmosphere, both the velocity and the tilt are explainable. The tilt reflects that of Jupiter's magnetic field, since the fresh ions are gyrating at right angles to it. Although a similar phenomenon was observed several times in 1984, we still do not know how common it is.

THE SEPARATE SPECTRA OF PLUTO AND ITS SATELLITES CHARON . U. FINK

The mutual occultation event of Pluto and Charon has provided us with a unique opportunity to record their spectra separately. We have accomplished this for the occultation event of 1987 March 03. We were hopeful that the spectra would show some unusual features or surface constituents. Instead the methane absorptions that appear so strongly in their combined spectra could be attributed solely to Pluto while Charon showed a flat and featureless spectrum. Thus if Charon ever had any substantial methane component on its surface, its low surface gravity could not hold it and the methane evaporated and escaped.

STELLAR OCCULTATION BY PLUTO . . . . . J.L. ELLIOT, R.L. MILLIS

The long-standing controversy of the existence of an atmosphere on Pluto has been resolved in the affirmative by observations of a stellar occultation by Pluto on June 9, 1988. The gradual—rather than abrupt—disappearance of the starlight is unambiguous evidence for an atmosphere. Reliable predictions for the occultation were issued by Dr. Lawrence Wasserman of Lowell Observatory. These enabled successful observations by Dr. Robert Millis of Lowell, with a portable telescope in northeastern Australia, and by Drs. James Elliot and Edward Dunham of MIT, with the Kuiper Airborne Observatory. Other observations were also obtained from sites in New Zealand and Australia. Further analysis of the data will reveal physical properties of the atmosphere, such as pressure, temperature, and number density profiles.

VISUAL AND INFRARED PHOTOMETRY OF PLUTO-CHARON MUTUAL EVENTS

E. F. TEDESCO

We have obtained visual (Johnson V band) observations of Pluto-Charon mutual events using the Palomar 1.5-meter and Kitt Peak 1.3-meter telescopes. These observations will be used to derive models of the Pluto-Charon system, including separations, relative sizes, some orbital parameters, system density, and (possibly) a crude albedo map of the hemisphere of Pluto facing Charon. We have also used the Palomar 5-meter and NASA IRTF 3-meter telescopes to obtain observations in the 1.5 to 2.3 μm wavelength region to investigate the distribution of methane and water frosts in the system. A third annual "Pluto Workshop" was organized and held in connection with the 1987 DPS meeting. Coordination of an international campaign to promote Pluto eclipse season studies was continued, primarily via the publication of a newsletter in cooperation with Marc Buie of the University of Hawaii.

PHOTOMETRY OF PLUTO-CHARON MUTUAL EVENTS. . . . . R. P. BINZEL

Once every 124 years, nature provides earth-bound astronomers with the opportunity to observe occultation and transit phenomena between Pluto and its satellite, Charon. Ground-based observations of these events allow precise physical parameters for the Pluto-Charon system to be derived which are unlikely to be improved upon until *in situ* spacecraft observations are obtained. This program supports photometry observations from McDonald Observatory, a critical location in an International Pluto Campaign network. Knowledge of the diameters, masses, densities, and compositions derived from these observations will augment our understanding of Pluto's origin and its context within the problem of solar system formation. Reduction and analysis of 1987 multi-color photometry has provided individual colors for Pluto and Charon and has shown they have relatively uniform hemispherical distributions (Binzel 1988a). During 1988, observations of 8 additional mutual events have been obtained or attempted.

HIGH RESOLUTION IMAGING OF SOLAR SYSTEM OBJECTS . . . B. GOLDBERG

The principal accomplishment of this program during the past year was to establish a continuing capability for carrying out observations of natural solar system objects at AMOS Observatory on Haleakala, Maui. In order to achieve this capability, it has been necessary to (1) develop and implement new sensor capabilities and observing techniques; (2) obtain USAF funding to support the required sensor development effort, which is based on mutual need; (3) modify the telescope control/tracking software; and (4) establish new capabilities for image processing. Preliminary comet observations have already been obtained and plans have been made to obtain observations of Mars with a very-high-resolution (but classified) imaging system during the current apparition. L. Broadfoot (Univ. of Arizona) is collaborating on the sensor program; F. Fanale (Univ. of Hawaii), R. Goody (Harvard), T. Maxwell (NASM), and R. Zurek, (JPL) will collaborate on the scientific program if the observations are successful.

Further progress was also made on processing the excellent comet imaging data set obtained with the 3.6m Canada-France-Hawaii Telescope between 1984 and 1987. Four Canadian collaborators are participating in this program. The data set contains high-resolution images showing the early coma (the first of Halley through the IHW filters) and the inner coma of the active comet. A comparison of one CFHT image of GZ with ICE magnetic field data (which was used to study the structure of the comet's ion tail) recently appeared on the cover of the AGU book Comet Encounters (A. J. Dessler, Editor). Representative CFHT and AMOS comet images have also been on display at the National Academy of Sciences for more than a year.

The Io sodium cloud movie produced from Table Mountain sodium imaging data continued on display at the National Air and Space Museum and will also be part of a traveling exhibit organized by the Smithsonian.

SPECTROSCOPIC PLANETARY DETECTION . . . . . D. DEMING

Monitoring of the apparent velocity of integrated sunlight continued. The purpose of the observations is to validate the spectroscopic method of detecting extra-solar planets, by measuring and intrinsic changes in the wavelengths of the solar absorption lines, and comparing these to the 13 meter/sec Doppler reflex due to Jupiter. In 1985 a 30 meter/sec change in the wavelengths of solar lines was seen, but data taken in 1987-88 show that solar wavelengths have returned to their pre-1985 values. It is still too early to tell whether these effects in solar type stars pose a serious problem for spectroscopic planetary detection efforts.

DISCOVERY OF SODIUM AND POTASSIUM VAPOR IN THE ATMOSPHERE OF THE MOON . . . . . **A. E. POTTER**

Spectra of the region just above the bright limb of the Moon show weak emission features which are attributed to resonant scattering of sunlight from sodium and potassium vapor in the lunar atmosphere. The maximum omnidirectional emission flux above the bright limb is 3.8±0.4 kiloRayleighs for sodium and 1.8±0.4 kiloRayleighs for potassium. The zenith column densities above the subsolar point are estimated to be $8X10^{+8}$ atoms/cm^2 for sodium, and $1.4X10^{+8}$ atoms/cm^2 for potassium. Corresponding surface densities are 67 and 15 atoms/cm^3 respectively. The scale height for the atmosphere is approximately 120 kilometers, which implies that the effective temperature of the sodium and potassium is close to the lunar surface temperature. The sodium density at the south polar region was found to be similar to that at the subsolar point, indicating widespread distribution of sodium vapor over the lunar surface. The ratio of the density of sodium to the density of potassium is 6/1, which is close to the sodium/potassium ratio in the lunar regolith, suggesting that the atmosphere originates from the vaporization of surface minerals.

PLANETARY ASTRONOMY AND SUPPORTING LABORATORY WORK . F.P. VALERO

During the last year we have completed work on the measurement of individual lines and manifolds in the spectrum of the 5μm fundamental Band of Germane which has been identified in the spectrum of Jupiter. Our measurements involve laboratory conditions appropriate for application to Jupiter. Besides, we have used a GeH_4 sample enriched in Ge^{74}. In addition, we also measured the intensities of some manifolds of the minor isotopes. A paper has been submitted reporting these results.

Progress has also been made on CH_3D. Line shape parameters, including low temperature broadening coefficients, have been determined, in particular using temperatures and collision partners of interest for planetary astronomy.

Our work on PH_3 (5μm and 8μm regions) related to the Jupiter atmosphere is under way. The very complicated laboratory safety requirements have finally been satisfied and progress in the acquisition of spectra is being made. Intensity and broadening coefficients depdendence on temperature have been determined for the CO_2 band at 2μm.

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